# NUTRITIONAL CHARACTERIZATION AND DETERMINATION OF PROCESSING SUITABILITY OF EDIBLE WILD CACTUS (*Opuntia spp*) FRUITS VARIETIES FOUND IN KENYA

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# Nutritional Characterization and Determination of Processing Suitability of Edible Wild Cactus (*Opuntia spp*) Varieties found in Kenya

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# DECLARATION

This thesis is my original work and it has not been presented for a degree in any other university

Signature……………………………. …………………Date………………………

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**JKUAT-Kenya**

## DEDICATION

This thesis is dedicated to my parents Augustus Mutunga (late) and Christine Mutwa, my lovely wife Beth Njambi, and siblings Aminah Mukuna Mutwa, Meshack Sogey, and George Nzivo with love.

Thanks for your love and support.

God has been faithful!

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## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| **AOAC** | Association of Official Analytical Chemists |
| **ASALS** | Arid and Semi-arid Lands |
| **CAM** | Crassulacean-acid Metabolism |
| **CD** | Cactus Drink |
| **CJ** | Cactus Jam |
| **CM** | Cactus-Mango |
| **CP** | Cactus-Pawpaw |
| **DPPH** | Diphenyl-1-picryl hydrazyl |
| **F.R.S.A.** | Free Radical Scavenging Activity |
| **G.A.E** | Gallic Acid Equivalent |
| **HI** | Harvest Index |
| **HPLC** | High Performance Liquid Chromatography |
| **ICARDA** | International Centre for Agricultural Research in the Dry Areas |
| **JKUAT** | Jomo Kenyatta University of Agriculture and Technology |
| **KALRO** | Kenya Agricultural and Livestock Research Organization |
| **Q. E** | Quercetin Equivalent |

| | |
|---|---|
| **RAE** | Rehabilitation of Arid Environment |
| **RUE** | Rain Use Efficiency |
| **TTA** | Total Titratable Acidity |
| **TSS** | Total Soluble Solids |
| **UV-Vis** | Ultra-violet visible spectrophotomètre |
| **WUE** | Water Use Efficiency |

## ABSTRACT

Edible wild cacti (*Opuntia spp.)* are considered to have a promising commercial application in the food industry due to their nutritive composition and drought resistant nature. However, knowledge on their nutritive composition and processing suitability in Kenya is still limited. This study sought to identify the main edible wild cactus varieties in Kenya and determine their nutritional characteristics in order to unlock their industrial potential. Cactus plant descriptors based on FAO-ICARDA Cactus Net guidelines were used to identify the edible cactus fruit varieties from four Kenyan Arid and Semi-Arid lands (ASALs) counties (Machakos, Baringo, Makueni and Laikipia). The estimated yields, morphological, physicochemical, and sensory quality parameters of the fruits were determined and fruit-based products were processed. Three edible cactus fruit varieties were identified namely: *Opuntia stricta* (purple), Opuntia *monacantha* (green) and *Opuntia Ficus-indica* (yellow). The purple variety had the highest yields (> 11kg/ $m^2$). At the ripe stage, the juice recovery rate for the purple and yellow varieties was above 50%. The three varieties were a rich source of crude fiber (1.41-1.71g/ 100g), Potassium (106.21-203.71 mg/100g), Magnesium (62.9-123.86 mg/100g), and Zinc (2.30-2.39 mg/100g). The sugar content was predominantly glucose (1.26- 4.59 g/100g) and fructose (1.45-2.66 g/100g) with the yellow variety having the highest. The fruits exhibited substantial amount of total phenolics (1.79-2.52 g/100g G.A.E.) and high antioxidant activity (0.59-1.83 mg/ml), which was highest in the purple variety. Based on the sensory analysis, the yellow variety was considered best for fresh consumption. The purple variety had superior physicochemical characteristics suitable for commercial processing. The acceptability of the fruits and fruit-based products evaluated was above five (5) on a 9-point hedonic scale. This shows the potential of the fruits to be used either in isolation or with other food ingredients in the food industry.

# CHAPTER ONE

# INTRODUCTION

## 1.1. Background Information

In the recent past, most consumers have expressed their interest in processed food products that enhance balanced diet, have high nutritional value, and are rich in bioactive compounds (Cota-Sánchez, 2016) The bioactive compounds play a major role in prevention and/or management of lifestyle diseases (He & Giusti, 2016). Several studies have reported health benefits of bioactive components in food to human health and referred to as functional ingredients. The foods containing such functional ingredients are characterized as functional foods (Dantas, *et al.*,2015). Therefore, functional foods can be defined as foods that not only achieve their elementary nutritional functions, but also have health benefits to the body and reduce risk of diseases ( Dantas, *et al.*, 2015 ). The demand for natural products and health promoting foods including cactus has been on rise due to the increased consumer awareness of the health benefits of foods (Inglese *et al*., 2017) . Several health-promoting compounds have been identified in many fruits such as apples, grapes, and the prickly pear cactus amongst many others (Nazareno, 2014). However, exploitation and utilization of wild fruits such as edible wild cactus is still limited in Kenya (Kunyanga, *et al.*, 2014).

The edible wild Cacti belong to cactaceae family and include the cactus pear (*Opuntia spp*.) varieties such as *O. Ficus-indica*, *Megacantha, O. monacantha, O. joconostle, O. Mutadae and O. Robusta* ( Saenz, 2013). The *Opuntia spp*. is native to tropical and sub-tropical America, where it grows either the wild or it is cultivated in home gardens. Consequently, as people continued to trade and settle, the plants were distributed to other parts of the world including Africa, Asia, Australia, and Europe (Chessa, 2010; Liguori & Inglese, 2015).

In Kenya, most of the cactus species are found in the drier regions of Eastern, Coast, North Eastern, Nyanza, and parts of Rift-valley provinces (Omweri, *et al*., 2016 ). The

*Opuntia* species are widely distributed in Laikipia plateau majorly in west Doldol. This is attributed to shift in land use pattern and degradation of the arable and rangeland (Kunyanga *et al.,* 2014). In a bid to search for profitable and climate-smart crops amidst the increased global warming phenomenon, cactus has emerged as a suitable crop. This is characteristic to its morphological and physiological characteristics that make it suitable to survive through the prevailing weather conditions ( Liguori & Inglese, 2015). The fruit is a berry with a thick peel enclosing a delicately flavoured seedy pulp (Saenz, 2013). The stems have been modified to succulent pads to retain as much moisture content as possible and the leaves have been reduced to spine to reduce the transpiration rate (Omweri, *et al*., 2016).

## 1.2 Problem Statement

Production of drought-resistant crops including cacti (*Opuntia spp*.) is limited in the Kenyan Arid and Semi-arid Lands (ASALs) that account for over 80% of the total dry land mass ( Omweri, *et al*., 2016). With increasing global warming, overdependence on rain-fed Agriculture has always led to crops failure, frequent drought, and famines in the ASALS (Saenz, 2013). The adpotion of cactus as a regular crop is at its infancy stages attributed to limited initiatives by Agricultural research organizations and the government to promote the crop. Besides, most of the communities in the ASALS where the cactus grow are nomadic pastoralists, who practice minimal crop cultivation and thus domestication of the crops becomes a major challenge. More to that, drought tolerant crops such as cactus are underutilized due to lack of sufficient information on their safe handling methods, nutritive and health benefits (Kunyanga, *et al.*,2014). The management policies by Kenya Plants Inspectorate Services on potential utilization of cactus are at infancy that has limited the full exploitation of the climate-smart crop.

## 1.3. Justification of the Study

With increased global warming phenomenon, the search for climate-smart crops including cactus is inevitable. Cactus has good Water Use Efficiency (WUE) and good Rain Use efficiency (RUE) than any other convectional food crop and its utilization can diversify agriculture, livelihood, and subsistence-based crops (De Waal, *et al.,* 2015).

Information on the utilization of edible wild cactus species could be useful for the adoption of the crop in the ASALS that could contribute immensely on food and nutrition security for the ASALS communities. In Mexico, domestication of edible cactus varieties has been a success with various applications for commercial juice processing and breeding programs (Inglese *et al.,* 2017). The Food and Agricultural Organization (FAO) and International Centre for Agricultural Research in the Dry Areas (ICARDA) Network (FAO-ICARDA Cactus Net) have made several attempts to research on various uses of cactus as food.

Proper documentation on safe handling methods and processing of the cactus produces into various shelf-stable products, it could be possible to reduce malnutrition and improve living standards of people living in the ASALS (Kunyanga *et al.,* 2014; Cota-Sánchez, 2016). Moreover, widespread knowledge on effects of diet on diseases, health care cost, and aging population has led to increased demand for natural health products resulting in cases where demand exceeds the supply, prickly pear cactus being an example of such underutilized crops and hence this demand could stimulate exploitation of the crop ( Nasr, 2015; Chessa , 2010).

In conclusion, research on the locally available cactus could add to the existing body of scientific knowledge and aid in validating information on its suitability for application in the beverage industry, and conservation of cactus resource in situ and ex situ for further research and use in the future. Therefore, this research highlights the potential utilization of edible wild cactus fruits with a view of formulating future policy recommendation on its economic potential to the ASALS communities.

## 1.4. Objectives

### 1.4.1. Main Objective

To determine nutritional characteristics and determine their processing suitability edible wild cactus fruit varieties in Kenya.

### 1.4.2. Specific Objectives

a) To identify the main varieties of edible wild cactus fruits found in Kenya
b) To evaluate physico-chemical characteristics of the identified edible cactus fruits varieties in Kenya.
c) To determine nutritional and phytochemical characteristics of edible wild cactus varieties in Kenya.
d) To determine the processing suitability of the identified edible wild cactus fruits.
e) To determine the acceptability of the fresh and processed cactus -based fruits products.

# CHAPTER TWO

# LITERATURE REVIEW

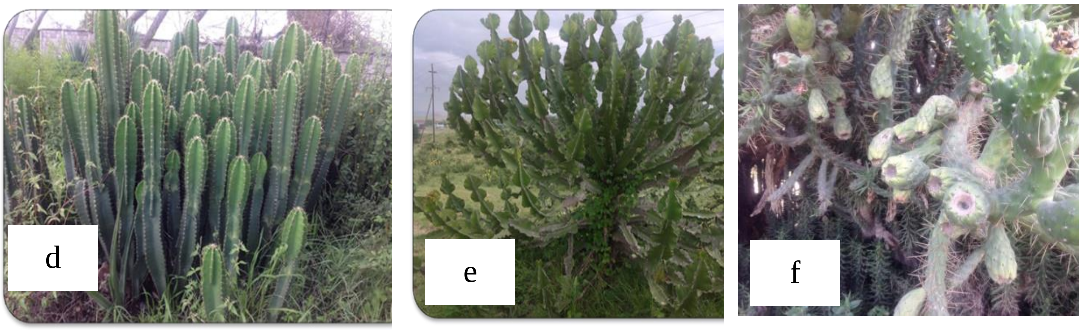
## 2.1 Origin, Agro-Ecological Distribution, Soils, Rainfall, Temperature

Cacti belong to Opuntia species, which have their origin in the tropical and subtropical America where they are either cultivated or grow in the wild (Inglese *et al*., 2017, Omweri, 2016). The genus has both edible and non-edible species **(Figure 2.1).**


**A. Morphological differences of edible wild cactus varieties**

**a)** ***O. Stricta***

**b)** ***O.Monacantha*** **c)** ***O.Ficus-Indica***




**B. Morphological differences of Non-edible cactus varieties in Kenya**

**d)** ***Thrixanthocereus blossfeldiorum*** **e)** ***Uphorbia ingens*** **f)** ***O.exaltata***

**Figure 2.1: Morphological differences of edible and non-edible cactus varieties**

**Source: (Omweri *et al.*, 2016)**

Cacti (*Opuntia spp.)* are extensively distributed in the tropical Mexico up to Colombia, in the Mediterranean basin mainly in the islands including Micronesia islands, Australia, tropical and southern Africa, western United States of America, Caribbean islands, temperate Asia and Hawaii (Inglese *et al*., 2017). Studies show that there has been increasing invasion of the Opuntia cactus species in the abandoned Mediterranean agricultural fields (De Waal *et al*., 2015). In Kenya, two species of Opuntia are common (*O. monacantha* and *O*. *Stricta*.) (Omweri *et al.*, 2016).

Cacti thrive well in Kenyan ASALs that account for over 80% of the total dryland mass including Baringo, Makueni, Machakos, Kitui, Nyeri North, Laikipia North, and Laikipia East. Cacti grow well in sandy, rocky, and well-drained soils. The rocks aid in decreasing the diurnal variation of soil water availability and increasing root growth and branching. However, they can adapt to a wide variety of soil types with a depth of 60 cm suitable for development of its roots system. ( Inglese *et al*., 2017).

Cacti are relatively tolerant to water stress but at the same time  sensitive to salinity. In spite of them being tolerant to water stress, Cacti do not do well in salty areasas evidenced stunted growth (Saenz, 2013; Chessa, 2010). However, they are tolerant to moderate salinity. Cacti are sensitive to freezing temperatures below negative six (-6$^{o}$C) and tolerant to high temperatures up to 65$^{o}$C (Nefzaoui, *et al*., 2013). In agronomic practices use of fertilizers rich in Nitrogen, Phosphorous, Calcium, and Potassium have shown to increase fruit production as described by Coetzer, & Fouche (2015) and Inglese *et al.,* (2017). Their ecological distribution in Kenya is shown in **Figure 2.2.**

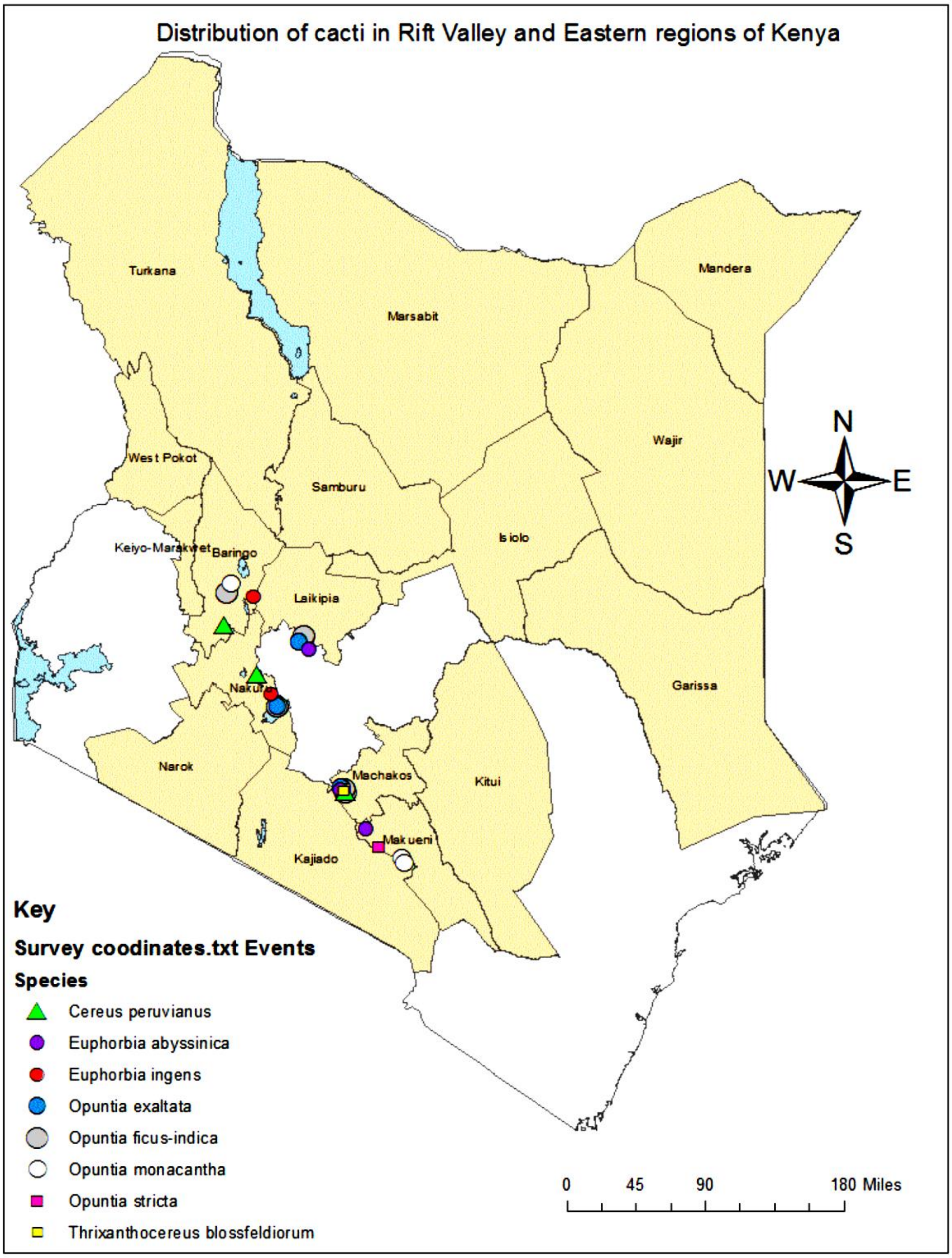



**Figure 2.2: Cactus Potential growth areas in Kenya**

**Source: (Omweri *et al*., 2016)**

## 2.2 Cactus Biological and Morphological Description

The cactus pear taxonomy is intricate with high variation in phenotypic characteristics, which is dependent on the prevailing environmental conditions (Liguori, G. & Inglese, P., 2015; Omweri *et al*., 2016). They reproduce either sexually or asexually and have several interspecific hybrids that exhibit high polyploidy (Nefzaoui, *et al*., 2013). Cacti (*Opuntia spp.)* belong to the cetacean family that contains about 130 genera and 1500 cacti species and are native to the ASALS of North and South America (Saenz,2013). Cacti are xerophytes, which means that they are physiologically and morphologically adapted to coping with extreme water deficiency in the ASALS. They have succulent stems and roots consisting of a spongy tissue that can hold water during the rainy season. The scientific classification of cacti species is as shown below:

| | |
|---|---|
| Kingdom: Plantae | Subfamily: Opuntioideae |
| Division: Magnoliophyte | Tribe: Opuntieae |
| Order: Caryophyllales | Genus: Opuntia |
| Family: Cactaceae | Species: *Opuntia spp* |

Cactus stems have leaves that have been modified into spines that can be as long as 15 cm to aid in minimizing water loss due to transpiration and act as defensive mechanism against birds and animals ( Inglese *et al*., 2017).

The stems are photosynthetic thus; the leaves are not required for photosynthesis. They undergo Crassulacean-Acid Metabolism (CAM) in which atmospheric carbon (IV) oxide is taken during the night when the stomates are open, fixed into four-carbon organic acids and later released within the plant to be utilized as sugars during photosynthesis (Chalak *et al*., 2012). It can withstand prolonged period of drought and thus it is considered as a potential alternative food crop for the ASALS' communities and the cladodes have multiple applications in cosmetic, biogas and animal feed industry. Its flowers vary from yellow to orange in colour and most of them boom during the night and are pollinated majorly by the nocturnal animals including bats and insects like the moth (*Inglese et al.,* 2017).

Cactus fruits are berries with thick peel enclosing a delicately flavoured seedy pulp. Cactus seeds are contained inside the fleshy pulp of the berry thus; vertebrates such as birds, wild pigs, and lizards that feed upon the fruits disperse them. Many of its seedlings are found beneath trees that are used as perching places for birds (Humair,*et al*., 2015). It can be propagated from the seeds or via vegetative reproduction from the cladodes (Omweri *et al.*, 2016). The scattered fruits containing the seeds are scattered during its dispersal and the seed germinate after long rainy period and warm temperatures above 21$^{o}$C. The seeds show slow germination due to their hard-lignified integument that hinders radical and plumule penetration (Inglese *et al.*, 2012). Besides, they have low yields of oil but rich in essential fatty acids, sterols, carotenes, and fat-soluble vitamins (Mbatchou *et al.,* 2012).

**2.3 Eco-Physiological Factors**

The position of the cladodes (Vertical, horizontal and so on) has influence on the photosynthetic activity (Chalak *et al.*, 2012) .The verticals with small insertion angels intercepts less light than the horizantals. Cactus pear has fixed photosynthetic organs thus physiological mechanisms intercept environmental messages that let them orientate their developing cladodes so that the exposure to sunlight is incresed for maximum photosynthetic activity (Omweri *et al.,* 2016). However, even though the plant orientates some of its cladodes to a favorable position , there exists restrictions to the sunlight it can absorb since they are fixed and thick, which keeps the sunlight from reaching the internal cladodes (Saenz,2013). In this case, shaping, prunning must be aimed at obtaining a less self-shading as the growth habitus is a very important factor to be considered. Shading has negative effects on productivity since sunlight is needed to differentiate flower shoots. Shaded cladodes reduce photosynthetic activity and conversely to what happens in other plants, remain on the plant and consequently need energy to stay alive.

## 2.4 Cactus Uses in Other Parts of The World

The cactus pear fruits and cladodes can be processed into various food products, by-products, and additives. The cactus products are shown in **Table 2.1** below:

**Table 2.1: Cactus products**

| Fruit | Cladodes | Fruits and cladodes |
|---|---|---|
| Juices and nectars | Juices, Alcohol, Sauces | Oil from seeds |
| Jams, gels, and jellies | Pickled and brine-cured products | Mucilage from cladodes |
| Dehydrated fruits, leathers, sweeteners, | Jams and jellies | Pigments from peel and fruit |
| Canned fruit | Flours & confectionary, | Dietary fiber from cladodes |
| Alcohols, wines, and vinegars | Young stems (Nopalitos) | Pulp for animal feed from peel and seeds |
| Frozen fruit and pulp | | |

The fruits are consumed fresh or processed into various value-added products including jams, jellies, sauces, juices, and wines ( Inglese, *et al.*,2012). The cladodes are processed into various products for use as raw material in brewing and confectionary industry and as a fodder. The seeds are dried and ground into powder for use as flours or for oil extraction.

## 2.5 Attempts for Cactus Utilization as Food by Farmers in Kenya

Cactus was probably introduced in Kenya by white settlers in the dry areas of Laikipia as markers for ranch boundaries or for some other purposes like beauty or livestock feeding ( Omweri *et al*., 2016). The plant gradualy spread in large tracts of land in Laikipia, Baringo and Nyeri North that was attributed to dispersal in faecal matter of livestock and wild life. The local communities in most parts viewed the plant as obnoxious weed and appealed to the governent to eradicate them. However, with the prolonged drought in the year 2008, the crop was seen as alternative fodder crop by the Non-Governmental organization (NGO), Rehabilitation of Arid Environment (RAE) .

Moreover,researchers from KALRO-Embu have researched on the nutritive value of the cactus cladodes and recommended on its various applications for animal feed processing. This created platform for further research on the suitability of the crop for fodder and its utilization for human consumption. In Kenya, researchers including Chiteva & Norman (2012) and Kunyanga *et al*., (2014) researched on nutritional significance of only one of the cactus species ; *Opuntia stricta* and recommended its use eitheir in isolation or alone for food and commercial processing.

## 2.6 Cactus Yields under Cultivation

The cactus yields vary considerably depending on the orchard management practices and the prevailing weather conditions (Boujghagh & Bouharroud, 2015). They are classified as CAM plants and thus have higher biomass yield than C3 and C4 plants.The yields range from 8-11 tonnes/hectare in dry land ranges and upto 22 tonnes/ hectare with irrigation and fertilezer application Arba, et al., 2015 ; Dubeux *et al.*, 2015 b) and Boujghagh & Bouharroud, (2015). The Maximal annual above ground dry weight productivities of various plant groups is shown on **Table 2.2** below:

**Table 2.2: Maximal annual above ground dry weight productivities of various plant groups in Mexico**

| Group | Annual Productivity (tons hectare$^{-1}$year$^{-1}$) |
|---|---|
| Opuntia (*O. Ficus-indica*) | 45-50 |
| Other CAM species (*A. salmina, A. tequilana, Ananas cosmosus*) | 35 |
| C3 Crops (Beta *vulgaris, Medicago sativa, Triticum Aestivum*) | 35 |
| C4 crops (Zea *mays. Sorghum bicolor, Saccharum officinarum*) | 49 |

Various agronomic attributes are taken into consideration in cactus fruits prodution as described by Coetzer & Fouche (2015) and include productivity of the cultivar,quality,resistance to diseases/hardening degree, longeivity of the fruit in the plant (the fruit should not show natural senesence a few days after ripening), and fruit harvest manegement, packing and transportation harding degree (Hammami*, et al.*, 2015). The fruit yields per hactare vary depending on the season and cultivar with ranges of over six tons per hactare upto 27 tons per hactare being recorded by Coetzer & Fouche ( 2015) in the Free state of South Africa.

### 2.7 Post-Harvest Handling and Processing of Cactus Fruits

Several Cactus pears are non-climacteric fruit with low ethylene rate at temperatures of $20^0$C and a low respiration rate ( Sáenz, (2013). The main post-harvest challenge of cactus is fruit decay and dehydration. Fungicides, waxes, and edible films have been used to reduce decay and dehydration in various countries including Italy, Mexico, and Chile (Inglese *et al*., 2017) . In the recent times, the use of heat treatment to control post-harvest decay has become of increased interest. For instance, in Italy the use of heat treatment shows potential of extending the shelf life for four to six weeks (Sáenz, 2013). In Kenya, the Twala women group produced juices and syrups in a bid to preserve the cactus fruits that were not characterized for their technological characteristics. However, the products had short shelf life of three to six days with challenges of discoloration (Kunyanga, *et al.,* 2014).

### 2.8 Physico-Chemical Characteristics of Cactus Pear Fruits

The cactus fruits appear in different colours including purple, green, and orange and yellow attributes to the concentration of the betalains pigments including eighteen betaxanthins (Yellow color) and six betacyanins (Red-violet color). The fruits are non-climacteric implying that the don't ripen after harvesting, since they do not store starch as a reserve carbohydrate (Nazareno, 2014). Therefore, it is critical to harvest them at the optimal maturity for either processing or fresh consumption. The optimal maturity stage is determined by various factors including fruit size, fill of the fruits, changes in peel colour, fruit firmness, recepticular scar position, total soluble solids (TSS), and fall of the glochids (Liguori & Inglese, 2015). However, the fruits harvest index (HI) has not been systematically studied as described by De Wit, et al., (2014). The edible parts of the cactus pear fruits include the pulp and seeds. The yield of the pulp is an important factor for processors, as they prefer higher yields for commercial exploitation. The seed number is an important factor in genetic programs for breeding purposes. It also includes the palatability of the seeds whether hard or soft to chew ( Inglese *et al*., 2017).

The TSS increase rapidly 40-50 days after the setting as the color begins to change and can attain level of up to 12-15 °Brix when the fruit is fully ripened. With ripening, the sugars, TSS, and Vitamin C content increase to large extent as the fruit firmness and acidity begin to fall. The total soluble solids are attributed to the sugars including glucose and fructose found in the fruits at the last developmental stages (Cota-Sánchez, 2016). Furthermore, the sugars in the fruits are relatively stable after harvest that determines its quality parameters. The viscosity of the fruit pulp is an important factor used to determine the post-harvest behaviour of the fruits (Cota-Sánchez, 2016). The fruits are rich in pytochemicals including Vitamin C, phenolic compounds and flavanoids that are of health benefits to the human body (Dantas *et al.,* 2015). The content of the phytochemicals increase during ripening, which translates to increase of antioxidant activity by capturing free radicals.

### 2.9. Nutritional Characteristics Of Edible Wild Cactus Fruits Varieties

The nutritional compostion of the cactus shows that they are rich in the moisture content (83-90 %) attributed to their succulent nature to survive harsh climatic conditions, low in fat and protein (< 1%), and high in fibre (> 1.2 %) (Chiteva,.& Wairangu, 2012; Cota-Sánchez, 2016;. Kunyanga, *et al.,* 2014). The are good source of minerals including Iron and Zinc that could aid to aleviate micronutrient deficiency in the ASALS (Kunyanga, *et al.,* 2014).

### 2.10. Phytochemical Properties of Cactus

Functional foods may be defined as any food or food ingredients that provide a health benefit beyond its own traditional nutrients (He & Giusti, 2015). Cactus fruits have similar nutritional properties as other fruits but their technological properties pose a challenge during processing as they are ranked as low acid fruits thus sterilization treatment is required to prevent growth of pathogenic microorganisms.

Research on cactus functional properties has been carried out, which indicates that cacti are rich in Betalains pigments (Yahia, & Mondragón, 2014). Betalains are found in ten (10) families of the *Caryophyllaceae* and are nitrogenous Chroma alkaloids. The presence of Betalains excludes that of anthocyanins (Coria Cayupán, et al., 2015). They are stable in a pH range of 4 to 7, thus they are particularly utilized as food colorants in low-acidic foods. Betalains found in cactus pear include betacyanins (red-violet colour) and betaxanthins (yellow colour), in amounts like the most betalains rich red beet hybrids, considering the whole fruit (Sáenz, 2013; Cota-Sánchez, 2016). Betalains show anti-inflammatory activity  in vitro and in vivo from clinical trials that make them useful in commercial application for food supplements and pharmaceutical industries  (Avrelija & Chingwaru, 2014). Their health enhancing benefits make them suitable for use as adjunctive therapy.

Cactus pear fruits therefore, could be an even better source of betalains than red beet, which sensory problems due to high levels of the earth-like flavour compound called geosmin. Cactus pear is richer in vitamin C content than most of the other fruits including pears and apples that makes it a suitable for reduction of oxidative stress (Avrelija & Chingwaru, 2014). With increased knowledge on their nutritional value, processing of cactus fruits into a variety of value-added products has been on the rise to meet the need for diversification, increased shelf life and more convenience (Chiteva &Norman 2012; Kunyanga *et al*., 2014).

# CHAPTER THREE

# MATERIALS AND METHODS

## 3.1 Sample Collection and Identification

Sample collection was conducted in four Counties, which have the largest population of wild cactus in Kenya namely Makueni, Machakos, Baringo, and Laikipia for 17$^{th}$-19$^{th}$ Day of June 2015. This was during their peak fruiting season that begins from May to August for seasonal crop and December to March for out of season crop. Fruits from wild growing edible cactus varieties from selected regions at the same harvest maturity (> 50 % colour full) were picked on random purposive sampling criterion based on safety where there were no wild animals.

The geographic distribution of the samples collected is as indicated in **Table 3.1**

**Table 3.1: Geographic distribution of the samples collected for analysis**

| **S. No** | **Variety/location** | **Location of sampling** | | | |
|---|---|---|---|---|---|
| | | Machakos[1] | Makueni[2] | Laikipia[3] | Baringo[4] |
| | Latitude | 02.153510S [1b]<br>01.455310S [1c] | 02.009160S[2a]<br>02.106180S[2b] | 00.012410S [3c] | 00.470600N [4a] |
| | Longitude | 037.602330E[1b]<br>037.049180E[1c] | 037.366820E[2a]<br>037.586170E[2b] | 036.670840E[3c] | 035.979770E[4a] |
| **1** | *O. Stricta* [a] | x | ✓ | X | ✓ |
| **2** | *O. monacantha* [b] | ✓ | ✓ | X | x |
| **3** | *O. Ficus-indica* [c] | ✓ | x | ✓ | x |

✓ = Sampled X = Not sampled

a, b, c =Varieties 1,2,3,4= Location

The identification of the samples was done using the FAO-ICARDA Cactus Net plant descriptors (Inglese *et al.*, 2017). Residents with traditional knowledge of differentiating edible cactus varieties from non-edible cactus varieties were interviewed. The parameters observed for the fruit maturity included change in peel color, firmness of the fruit, fall of the glochids, increase in the size, and depth of the receptacle (Inglese *et al.*, 2017).

The methodology flow chart is shown in **Figure 3.1**:

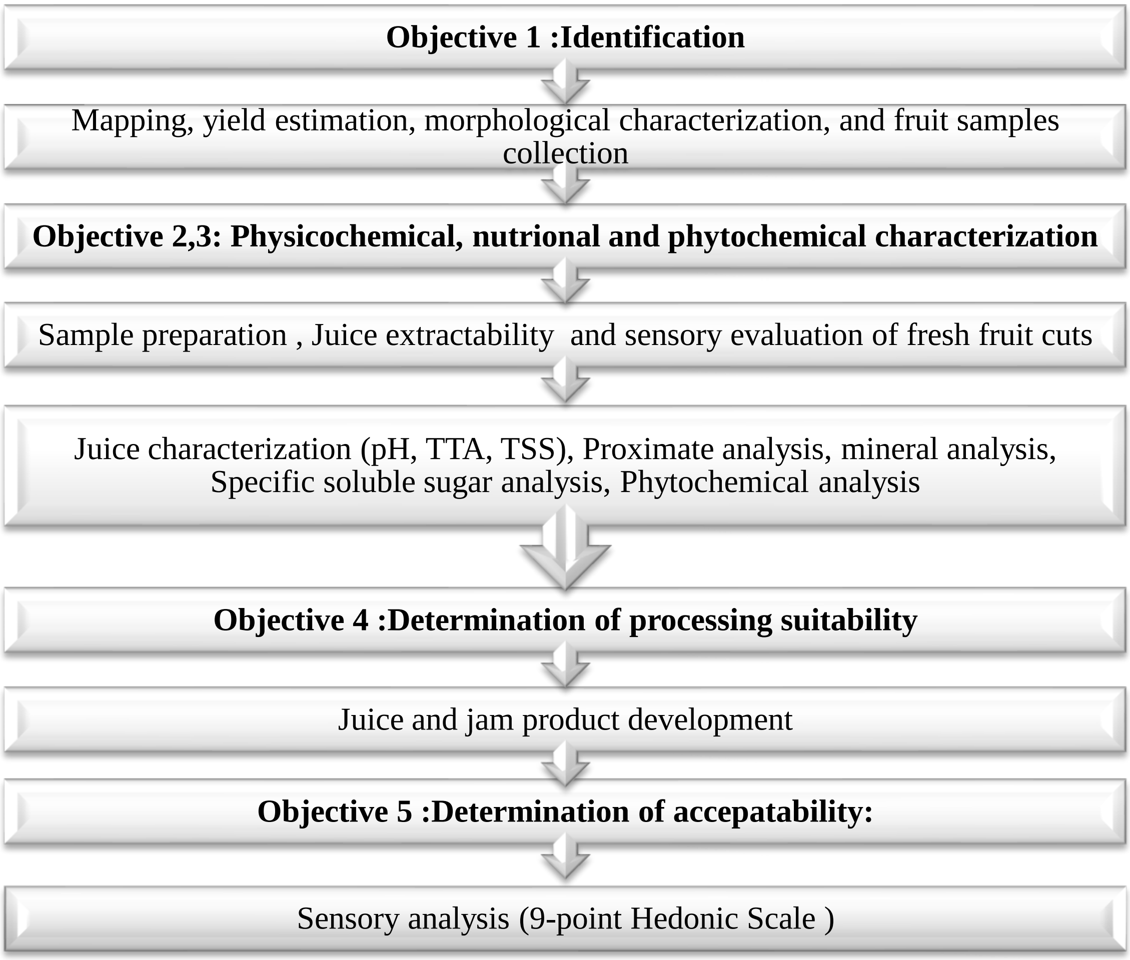



**Figure 3.1 Methodology Flow Chart**

### 3.2 Yield estimation

The yields of the cactus varieties were estimated by counting the average number of fruits per square meter at three different sample plots in each of the regions visited using the crop-cut method procedure outlined by Fermont and Benson, (2011). In this method, the yield in one or more subplots that are at least 1m$^2$ is measured and the yield per unit area calculated as total production divided by the total harvest area of the plot. The weight/$m^2$ was then determined by multiplying the fruits number per square meter and average fruits weight of the sampled fruits that represented the fruit density.

### 3.3 Morphological characterization of the cactus varieties

The shape, recepticular scar position, size and pulp colours were determined by visual observation and compared to fruit descriptors described by (Belay,*et al*.,. 2011). These attributes included fruit shape (ovoid, round, elliptic, and oblong), recepticular scar position (elevated, flattened, sunken) and fruit size [(Very small (<80g), Small (81-120 g), Medium (121-150g), Large (151-200g) and very large (>200g)] and fruit pulp colour (Orange, green, purple, yellow, red).

The weight of 25 fruits from each location was then determined accurately using a weighing balance. Each fruit was at that point separated into three parts (skin, flesh, and seeds) using a kitchen knife. The average weight of each part was accurately determined and expressed as proportionate composition of the whole fruit.

The sensory evaluation of the fresh cut fruits was done by a team of thirty (30) semi-trained sensory panellists to rate for sweetness and crushability of the seeds.

### 3.4 Sample preparation and juice extractability

Mature ripe fruits at the same harvest maturity were harvested and transported to Jomo Kenyatta University of Agriculture and Technology food technology workshops for analysis. The fruits were thoroughly cleaned using scrubbing pad and anti-bacterial soap to remove the glochids, eliminate dirt, and reduce microbial load as outlined in JKUAT food technology training manual. The fruits were then stored in cold rooms at $7^0$C±2 and relative humidity of 95% until analysis. The juice was extracted using a juice extractor (RM/204-Ramtons, China). Juice extractability was determined by weighing approximately 200g of sample (about 5 cactus fruits) prior to juice extraction. The weight of the juice recovered after extraction was quantified as a percentage of the initial weight of the samples. The juice that was not used immediately was kept under cold storage at -18$^oC$ for further analyses. All the physico-chemical analyses were done in triplicate.

## 3.5 Juice Quality Characterization

### 3.5.1 pH Determination

This was done by the method of Ofori and Hahn (2016) using a pH meter (TOA pH Meter HM–7B, Tokyo, Japan).

### 3.5.2 Total Soluble Solid (T.S.S.) Determination

The total soluble solid content was determined using hand refractometer (ATAGO model ATC-1, Tokyo, Japan) where three fruits at the same harvest maturity were blended to obtain juice that was measured and expressed as % $^0$brix.

### 3.5.3 Total Titratable Acidity (T.T.A) determination

The TTA was determined by titrating a specific volume of juice (approximately 10mls) of the sample against 0.1N NaOH (sodium hydroxide) in the presence of phenolphthalein indicator until faint pink colour was observed against a white background as described by Yumbya *et al*., (2014). The volume of Sodium hydroxide used was noted and TTA results were expressed as % citric acid, which is the main organic acid in cactus fruit as described by Ueda *et al*., (2014) using the formula:

$$\% citricacid = A * 0.0064 * 100 / V \qquad \text{eqn 1}$$

Where: A = ml of 0.1 NaOH required for the titration; and

V = ml of sample taken for the test.

0.0064 = Constant

### 3.6 Proximate Composition

The moisture content, crude fat and ash were determined as per methods 934.01, 920.39 and 923.03 respectively of the Association of Official Analytical Chemists (AOAC, 2016). Nitrogen percentage was determined using Kjeldahl method and a factor of 6.25 was used to convert the nitrogen percentage into crude protein AOAC 2016 (Method 960.52). For mineral composition, Calcium, Magnesium, Iron, Zinc, Potassium, Sodium, and phosphorous composition were determined using Atomic Absorption Spectroscopy (AAS) as described in 942.05 AOAC, (2016) Method.

#### 3.6.1 Moisture Content Determination

The moisture content was determined using AOAC (2016) method 934.01. Dishes (with covers) were heated to 105$^o$c, cooled in desiccators, and weighed accurately with analytical balance to determine weight of the empty dishes. About Five grams (5g) of well-pulped sample was accurately weighed into a moisture dish and transferred to a Hot-air-oven previously heated to temperatures of 105°C and drying was done for 1 hour. The final weight of the sample was taken after the drying period and cooling in a desiccator. The moisture levels were obtained using the formula below.

Calculations;

$$\%Moisture = \left( \frac{Weight.of\ sample\ before\ drying - Weight.of\ sample\ after\ drying}{Weight.of\ sample\ before\ drying}. \right) * 100 \quad \text{eqn 2}$$

#### 3.6.2 Analysis of Crude Fat

The Soxhlet method of extraction was used to extract the crude fat as described by AOAC (2016) method 920.39. About Five grams (5g) of samples were weighed into pre-weighed extraction thimbles and the initial weights of the flasks taken. Fat extraction was done using petroleum spirit in Soxhlet extraction apparatus for 8 hours. The extraction solvents were then evaporated and the extracted fat dried in a Hot-air oven for about 15 minutes before the final weights of the flasks with the extracted fat were taken

Calculations were done using the formula below;

$$Fat\ \% = \left( {Weight\ of\ fat\ extracted}/{Weight\ of\ the\ sample} \right) * 100 \qquad \text{eqn 3}$$

### 3.6.3 Protein Content Determination

The protein content determination was done using Semi-Micro Kjeldahl Method as described by AOAC (2016) method 960.52. About 1g of sample was weighed into a digestion flask together with a catalyst composed of Five grams (5g) of $K_2SO_4$ and zero point five grams (0.5g) $CUSO_4$ and 15ml of concentrated $H_2SO_4$. The mixture was heated in a fume hood until the digest colour turned blue to indicate the end of the digestion process. The digest was cooled, transferred to a 100ml volumetric flask, and topped up to the mark with distilled water. A blank digestion with the catalysts and acid was also made.

Ten millilitres (10mls) of diluted digest were transferred into the distilling flask and washed with about two (2) ml distilled water. Fifteen ml of 40% NaOH was added and washed with about 2ml distilled water. Distillation was done to a volume of about 60ml distillate. The distillate was then titrated using 0.02N-HCl to an orange colour of the mixed indicator, which signified the end-point. Calculations were done using equation 4 below:

$$Nitrogen\% = (v1 - v2) * N * f * 0.014 * {100}/{v} * {100}/{S} \qquad \text{eqn 4}$$

Where:

$V_1$ = Titre for sample (ml)

$V_2$ = Titre for blank (ml)

N = Normality of standard HCl solution (0.02)

f = Factor of standard HCl solution

V = Volume of diluted digest taken for distillation (10ml)

S = Weight of sample taken (g)

Protein % = Nitrogen × protein factor.

### 3.6.4 Ash Content

Dry-ashing method was used to determine ash content as described by AOAC (2016) method 942.05. Silica crucibles were first dried at 550$^{o}$C in a muffle furnace and cooled to room temperature in a desiccator. About 2 g of the samples were weighed in pre-conditioned crucibles. The samples were first charred by flame to eliminate smoking and then incinerated at 550°C in a muffle furnace to the point of white ash. The residue was cooled in desiccators and the weights taken.

Calculations were done as shown below;

$$Crude\,ash\% = \left( {Weight\,of\;Ash} \big/ {Weight\,of\;sample} \right) * 100 \qquad \text{eqn 5}$$

### 3.6.5 Crude Fiber

The crude fibre (non-soluble carbohydrate) content was determined using the AOAC method 991.43 (AOAC 2016). Approximately 2g (W) of sample was weighed into a 500ml conical flask. About 200ml of heated 1.25% $H_2SO_4$ was added and boiling done for 30min under reflux condenser. Filtration was done under slight vacuum with Pyrex glass filter (crucible type) and the residue was washed to completely remove the acid with boiling water. Approximately 200ml of boiling 1.25% NaOH was added to the washed residue and boiling done under reflux for another 30min. Filtration was done using the same glass filter previously used with the acid. The residue was rinsed with boiling water followed by 1% HCl and again washed with boiling water to rinse the acid from the residue. The residue was washed twice with alcohol and thrice with ether. It was then dried in a Hot-air oven at 105ºC in a porcelain dish to a constant weight ($W_1$). Incineration was done in a muffle furnace at 550ºC for 3hrs, the dish was then cooled in a desiccator and the final weight ($W_2$) taken as describes in AOAC, 2016 (Method 920.86-32.1.15).

Calculations were as shown below.

$$\%Crude\ fibre = \left(\frac{W1 - W2}{W}\right) * 100 \qquad \text{eqn 6}$$

Where;

$W_1$= weight of acid and alkali digested sample,

$W_2$= weight of incinerated sample after acid and alkali digestion and,

W= weight of sample taken.

### 3.7 Determination of Minerals

The determination of minerals (Ca, Mg, Fe, Zn, K, Na, P, Pb, and Cd) was done using the dry ashing method as described by AOAC (2016) Method no. 953.01. Cactus samples were ashed in a muffle furnace at 550ºc. The ash was boiled with 10ml of 20% hydrochloric acid in a beaker, which was then filtered into a 100ml standard flask and topped to the mark with deionized water. The resulting solution was micro filtered and the mineral constituents determined using Atomic Absorption Spectroscopy (AAS) against standard solution of the specific salts for each of the element. All the values were expressed in mg/100g.

### 3.8 Specific Soluble Sugars Determination

The specific soluble sugars (glucose, fructose, and sucrose) were determined using High Performance Liquid chromatography (HPLC) method as outlined in AOAC 2016 method 977.20. About 5 grams of homogenized fruit pulp was accurately weighed and dissolved in 100 ml distilled water in a 250 ml volumetric flask. Two ml of lead acetate solution were added and the mixture mixed thoroughly. The mixture was filtered thoroughly using cotton wool. Ten ml (10 ml) of sodium oxalate was added into the filtrate and the mixture was shaken vigorously. The mixture was then filtered again discarding the first few drops of the filtrate. One ml of the filtrate was filtered, mixed with acetonitrile 1:1, and kept safely in HPLC vials bottles for analysis.

The standard solutions (1-5 mg/ml) and the sample extracts were analysed using a HPLC auto sampler unit (HPLC Model SIL- 20A/C Shimadzu, Japan) fitted with a refractive index detector 10 A (Shimadzu, Japan). The conditions for analysis were; oven 35°C, flow rate: 1.0 ml/min, working pressure,57-68 Kgf/cm$^2$ injection volume – 20 μl, and column- Ashipak NH2P-504E. Standard sugar solutions of fructose, glucose, and sucrose were used to identify and estimate the concentration of the specific sugars in the samples from the linear curve equation y= Kx, and $R^2$.

K=Constant

Y= peak area

X= mass concentration

$R^2$ = Correlation coefficient

### 3.9 Determination of the Phytochemicals

The phytochemicals determined were Vitamin C, total carotenoids, total polyphenols, flavonoids, and free radical scavenging activity, which is attributed to the activity of the various phytochemicals.

#### 3.9.1 Vitamin C Determination

Vitamin C content was determined using 2, 6-dichlorophenol indophenol titrimetric method as described by AOAC (2016) method 967.21. About five grams of cactus pulp were diluted with 10% Trichloroacetic acid (TCA) to 100 ml mark of 100ml volumetric flask. 2, 6-dichlophenolindophenol was titrated to 10.0ml of the pulp filtrate. Vitamin C content (Ascorbic acid) was calculated as:

$$Vita\min C\ (mg/100g) = {(A-B)*C*100} \Big/ {S*(100/10)} \qquad \text{eqn 7}$$

Ascorbic acid, (mg/100g) = (A-B) X C X 100/s X (100/10)

Where:

A = Volume in ml of indophenol solution used in the sample.

B = Volume in ml of indophenol solution used for the blank

C = Mass in mg of ascorbic acid equivalent to 1 ml of standard indophenol solution.

S = weight of the sample taken (g)

100/10 = total extraction volume / volume of titrated sample

### 3.9.2 Total Carotenoids

The analysis of total carotenoid was done using the method of Rodriguez-Amaya and Kimura (2014). About five grams of homogenized cactus pulp was transferred into a mortar and 1.5 grams of cellite was be added. The mixture will be ground with 50 ml of acetone, which had been refrigerated 2 hours prior to use. The sample was then filtered with suction through a sintered glass funnel. The extraction was repeated until the residue and washing from the mortar were devoid of color. About 25 ml of petroleum ether was put in a separating funnel and a small portion of acetone added. Distilled water was slowly set to flow along the walls of the funnel. The two phases were then be left to separate and the lower aqueous acetone extract phase discarded, and more of acetone extract was added in small portion until it is over. The sample was then washed with water twice to remove residue acetone and the carotenoid extract put in a 50 ml volumetric flask and made to volume with petroleum ether. Total carotenoids content from the extract were then determined by taking the absorbance at

450 nm in a UV-Vis spectrophotometer (UV 1800, Shimadzu, Japan). The readings were converted β-carotene equivalent. The total carotenoid content was calculated using the formula:

$$Total\ Carotenoid\ Content\ (\mu g/g) =\rightleftarrows\ \frac{A*V(ml)*10^4}{A^{1\%}{}_{1cm}*P(g)} \qquad \text{eqn 8}$$

Where:

A =Absorbance

V = Total extract volume

$A_{1cm}^{1\%}$ = 2592 (β-carotene Extinction Coefficient in petroleum ether).

P = Sample weight

### 3.9.3 Determination of Total Polyphenols

Qualitative determination of total polyphenol was done using Ferric chloride test as described by Singleton et al (2015) in which the methanolic extract of the cactus samples was diluted to 5 ml with distilled water. To that, a few drops of neutral 5% Ferric chloride solution were added. A dark green or a blue-black colour indicated the presence of phenolic compounds.

For quantitative determination of total phenols, Folin-Ci ocalteu reagent was used as per method described by Singleton et al (2015). The amount of total phenolics was calculated from standard curve of Catechin hydrate (20-100 µg) and the results were expressed as g/100g Gallic Acid Equivalent (G.A.E.)

### 3.9.4 Extraction and Determination of Flavonoids:

Sample extraction for analysis of flavonoids was done as described by Harborne (2015). About Five grams (5g) of dried and crushed samples were weighed into a 250 ml conical flask and about 100 ml methanol added. The flask was closed securely using parafilm and covered with aluminium foil. The samples were put in a shaker and shaken for about 3 hours. They were then kept in the dark and left to extract for 72 hours. After 72 hours, the samples were filtered through Whatman No. 4 filter paper, and then the filtrate concentrated in a vacuum evaporator to a volume of 20 ml. The extract was transferred into vial bottles and securely stoppered. The extract was used for analysis of flavonoids and anti-oxidative activity.

First, qualitative determination of flavonoids was determined. Approximately 5 ml of dilute ammonia solution was added to a portion of aqueous filtrate of extracted sample followed by addition of concentrated $H_2SO_4$. If a yellow coloration was observed, it indicated the presence of flavonoids. The yellow coloration disappeared on standing for 3-5 minutes.

For quantitative determination of flavonoids, the Aluminium chloride colorimetric method as described by Jagadish *et al, (*2016) was used. The results were expressed as mg/100g Quercetin Equivalent.

### 3.9.5 Determination of the Free Radical Scavenging Activity

The radical-scavenging activity was determined using 2, 2-Diphenyl-1-picryl hydrazyl (DPPH) radical (Sigma-Aldrich) as described by Molyneux (2013). Cactus extracts of, 0.05, 0.1, 0.5, 1.0, 2.0 and 5 mg/ml concentrations were prepared in methanol in cuvette placed in the spectrophotometer (Analar grade). Vitamin C was used as the antioxidant standard at concentrations of 0.02, 0.05, 0.1, 0.2, 0.5, and 0.75 mg/ml. One ml of the extract was placed in a test tube, and 3 ml of methanol added followed by 0.5 ml of 1 mM DPPH in methanol. The mixture was shaken vigorously and left to stand for 5 minutes. A blank solution was prepared containing the same amount of methanol and DPPH. The absorbance of the resulting solution was measured at 517 nm with a spectrophotometer (Shimadzu model UV – 1601 PC, Kyoto, Japan). The radical scavenging activity was then calculated using the following formula:

$$\%Inhibition = \{[Ab - Aa]/Ab\}*100 \qquad \text{eqn 9}$$

Where Ab = the absorption of the blank sample and

Aa = the absorption of the samples.

All tests were run in triplicate and the results were averaged.

### 3.10 Juice and Jam Product Development

The formulation of the juice and jams products were developed through modified food processing procedures in JKUAT Food Science and Technology workshops. Ready to drinks juice samples (30 % juice content) were sweetened using sugar ratios of 60g/l, 80 g/l, and 100g/l of the juice. The jams were made with blends of 1:1 banana, mango, and pawpaw respectively attributed to high pectin content of the cactus pulp. The process flow diagram is as shown in **Figure 3.2**.

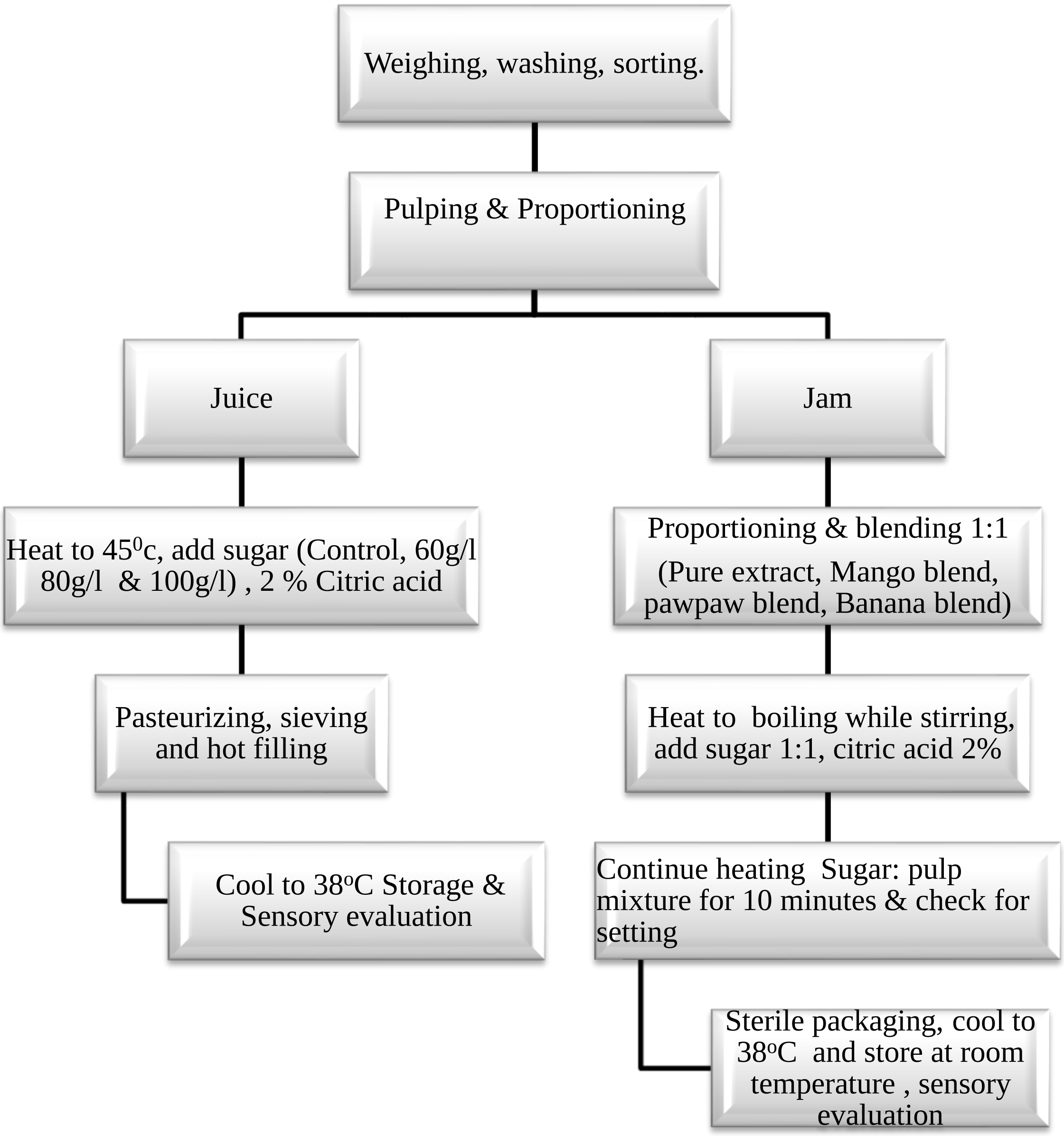



**Figure 3.2: Flow Chart for processing juice and jam products**

### 3.11 Sensory Evaluation

A team of 30 semi-trained sensory panellists were engaged in the sensory evaluation with their informed consent prior to the sensory evaluation. The products were rated for the colour, taste, aroma, flavour, and general acceptability of the products. The scores were ranked using the 9-point hedonic scale based on individual appreciation of the products (Migliore *et al.*, 2015).

### 3.12 Statistical Analysis

All the analyses were performed in triplicates and the results presented as mean values ± standard error. The data was statistically analysed with the Statistical Analysis Software (SAS) GenStat, 18$^{th}$ edition and the means separated using Least Significance Difference (LSD) at $p \leq 0.05$. Mean comparisons for treatments were made using Duncan's Multiple Range Tests.

# CHAPTER FOUR

# RESULTS AND DISCUSSION

## 4.1 Morphological Characteristics

The morphological characteristics of the cactus fruits were diverse in the three identified varieties in regards to shape, receptacle scar position, and color. The purple and green fruits were ovoid in shape whereas the yellow cactus fruit was oblong. The receptacle scar position for the green and purple fruit was flattened while for the green and yellow fruit was sunken. The colour varied from purple to yellow attributed to the ratio and concentration of betalains pigments as described by Yahia & Mondragón (2014). The results for the morphological characteristics for the cactus fruits are shown in **Figure 4.1** below.

***O. Stricta*** | ***O. monacantha*** | ***O. Ficus-Indica***

**(Purple variety)** | **(Green variety)** | **(Yellow variety)**

**Figure 4.1: Cross-sectional views of three edible wild cactus fruits varieties found in Kenya**

Researcherers described cacti fruits (*Opuntia spp.*) to contain twenty four(24) know/unknow betalain pigments including eighteen (18) betaxanthins (yellow color) and six (6) betacyanins (red-volet color) that were responsible for different colors. The difference in color signifies variation in the anti-oxidant activities (Du Toit *et al.*, 2015).

### 4.2 Physical Characteristics of Edible Cactus Varieties

The physical characteristics of the three edible wild cactus varieties varied significantly at ($p \leq 0.05$) as shown in **Table 4.1** below.

**Table 4.1: Physical characteristics of edible cactus varieties**

The results are presented as mean± standard error of three separate determinations

| Fruit Type | Eco-geographical zone | Average no. of fruits/m$^2$ | Average Fruit Wt.(g) | Fruit Yield Kg/m$^2$ | Flesh (%) | Skin (%) | Seeds (%) | Juice Extractability (%) |
|---|---|---|---|---|---|---|---|---|
| *O. Stricta* (Purple Variety) | Baringo (Marigat) | 342.00 ±2.31$^{b}$ | 32.38 ±0.05$^{a}$ | 11.07 ±0.09$^{c}$ | 51.38 ±0.41$^{a}$ | 27.23 ±0.72$^{a}$ | 21.55 ±1.09$^{c}$ | 50.89 ±0.02$^{cd}$ |
| | Makueni (Sultan) | 353.30 ±5.78$^{c}$ | 32.22 ±0.09$^{a}$ | 11.38 ±0.17$^{c}$ | 51.41 ±0.64$^{a}$ | 28.22 ±0.30$^{a}$ | 20.53 ±0.64$^{c}$ | 52.14 ±0.26$^{d}$ |
| *O. mona-cantha (*Green Variety) | Machakos (Kangundo) | 104.00 ± 3.06$^{a}$ | 58.39 ±0.98$^{b}$ | 6.07 ±0.09$^{a}$ | 57.66 ±0.63$^{b}$ | 32.58 ±0.66$^{c}$ | 9.75 ±0.05$^{b}$ | 32.79 ±0.34$^{a}$ |
| | Makueni (Nziu) | 104.70 ± 1.20$^{a}$ | 61.37 ±1.76$^{b}$ | 6.43 ± 0.11$^{a}$ | 57.79 ±0.36$^{b}$ | 30.82 ±0.04$^{b}$ | 11.61 ±0.43$^{b}$ | 38.16 ±1.10$^{b}$ |
| *O. Ficus-indica* (Yellow) | Laikipia (Matunda) | 99.3 0 ±2.40$^{a}$ | 78.74 ±3.68$^{c}$ | 7.82 ±0.38$^{b}$ | 59.07 ±0.31$^{b}$ | 33.51 ±0.05$^{c}$ | 7.50 ±0.31$^{a}$ | 50.37 ±0.34$^{c}$ |

(n=3). Means within the same column with different superscripts are significantly different at ($p \leq 0.05$). LSD = Least Significant Difference at 5% level of significance

The estimated yield per square meter did not vary significantly at $p \leq 0.05$ for the green and yellow cactus varieties. The purple variety exhibited highest yield per square meter (342 fruits/m$^2$), which is a good characteristic when considering commercial exploitation potential. The average fruit weight (g) and fruit density (Kg/m$^2$) varied significantly across the three varieties. The yellow variety exhibited the highest fruit weight (78.74 g) that would render it suitable for fresh consumption and commercial processing. Consequently, the purple variety had the highest fruit density (11.07 kg/m$^2$) that was desirable for commercial exploitation, as processors prefer high yielding varieties for commercial exploitation (Cota-Sánchez, 2016).

The proportion of the fruit parts (percentage) did not vary significantly at $p \leq 0.05$ for the green and yellow variety except for seed percentage. The yellow variety had the highest flesh percentage (59.07 %) and contained the least seed percentage (7.50 %), which is an important criterion for consumers attributed to their preference for preference of seedless (apirethnic) or little seeded fruits. The purple variety exhibited the highest seed percentage (21.55 %) that explains to its invasive nature of growth as the seeds are widely dispersed by animals after its consumption. The seed number is an important factor in genetic breeding programs since it is decisive in seed marketing (Omweri, *et al.*, 2016). Eco-geographical difference did not result in any significant difference ($p \leq 0.05$) in fruit characteristics and yield among the green variety samples.

The Juice extraction rate was over 50% in the yellow and purple varieties, while the juice extractability in the green types was low (< 40%). The juice extractability is an important quality aspect to both fresh fruit consumers and processors as it translates to higher monetary value for higher volumes (Coetzer & Fouche, 2015). The juice extractability percentage of over fifty was deemed suitable for commercial processing, which was the case for purple and yellow variety (De Wit, *et al.*,2014).

### 4.3 Juice Quality Characteristics

The juice quality characteristics of the three varieties varied significantly at $p \leq 0.05$. The fruits were moderately acidic with pH ranges from (4.01- 4.86). Fruits with pH values greater than 4.5 pose greater challenges for storage attributed to bacterial growth (Kunyanga *et al.*, 2014). The differences in the pulp characteristics are shown in **Table 4.2** below.

**Table 4.2: Juice quality characteristics of the different cactus varieties found in Kenya**

| Fruit Type | Eco-geographical zone | pH | TTA (%) | TSS ($^oBrix$) |
|---|---|---|---|---|
| ***O. Stricta* (Purple Variety)** | Baringo (Marigat) | 4.82 ± 0.01$^d$ | 0.38±0.00$^c$ | 8.47±0.07$^b$ |
| | Makueni (Sultan-Hamud) | 4.01 ± 0.01$^a$ | 0.37±0.00$^c$ | 7.47±0.07$^a$ |
| ***O. monacantha* (Green Variety)** | Machakos (Kangundo) | 4.47± 01$^c$ | 0.16 ± 0.00$^a$ | 7.30±0.21$^a$ |
| | Makueni (Nziu) | 4.24 ± 0.00$^b$ | 0.15 ± 0.01 $^a$ | 7.26±0.07$^a$ |
| ***O. Ficus-indica* (Yellow Variety)** | Laikipia (Matunda) | 4.85± 0.01 $^e$ | 0.32± 0.00$^b$ | 10.13±0.07$^c$ |

The results are presented as mean± standard error of three separate determinations (n=3). Means within the same column with different superscripts are significantly different at ($p \leq 0.05$). LSD = Least Significant Difference at 5% level of significance

Acidity plays a good role in determination of the product quality, which renders the fruit suitable for juice production. These differences may due to the variation in the altitude, cultivar/genotype, and environmental conditions (FAO , ( 2013); Coetzer, G.M. & Fouche, (2015)

The Total Titratable Acidity (TTA) of the different varieties varied significantly with the green variety having the lowest (0.15%) while the purple variety exhibited the highest (0.38%). Agro ecological zones did not result in significant differences at ($p \leq 0.05$) for TTA for the green and purple varieties respectively. The Total Titratable Acid contributes to the sensory characteristics of the fruits and quality determination that aids consumers and processors in making informed decisions on right harvesting time and suitability for processing (Coetzer,. & Fouche, 2015). The TTA for cactus fruits was slightly lower than form mangoes (0.5-1.5%), pineapples (0.6-1.0 %), and oranges (0.7-1.2 %) that are commonly processed in Kenya though in same range with banana (0.2-0.5%), and pawpaw (0.3-0.8%).

At the same maturity level, the Total Soluble Solids (TSS) had significant variation with the yellow variety exhibiting the highest TSS (10.13 $^o$Brix) while the green had the least (7.30 $^o$Brix). The moderately high TSS value in yellow variety is attributed to the hydrolysis of sucrose, which is the most common form of carbohydrate in the fruit. Sugars are found mainly in the pulp during the last developmental stages of the fruit, being glucose and fructose the main component in ripe fruits. The cactus fruits do not store starch as reserve carbohydrates since they are non-climacteric fruits. Their sugar content remains almost stable after harvest, which is a good criterion for determining fruit quality. Sugars are the main component of the fruit flavour and consequently of the consumer acceptance. They must be collected having less than 11 $^{o}$Brix if flavour problems must be avoided (Migliore *et al.*, 2015). The yellow variety had TSS above 10 $^{o}$Brix that was deemed suitable for pure fruits juice, fruits preserves and fruits compotes. The purple variety had a lower TSS (7.5-8.5 $^{o}$Brix) though comparable to oranges, pawpaw, and watermelon fruits (8-12 $^{o}$Brix) that would be deemed suitable for commercial exploitation. The green varieties had a lowest brix (<7.5 $^{o}$Brix) hence would pose a challenge for commercial exploitation and fresh consumptions.

## 4.4 Proximate Analysis

The proximate composition of cactus varieties studied varied significantly at $p \leq 0.05$. However, the results did not vary significantly for similar varieties collected from different ecological zones. The fruits had high moisture content (87.68 % -92.82 %) attributed to their physiological and morphological adaptations for harsh climatic conditions. This would pose challenge for their storage as the high moisture content would create a favourable environment for microorganisms including yeast and molds. Like in many fruits, cactus pulp contained low amounts of crude proteins (2%) and fat (<1 %). These ranges were comparable to that of reported other cactus varieties by Sáenz (2013).

The proximate composition of the cactus varieties  studied is as show in **Table  4.3**.

**Table 4.3: proximate composition (%) of cactus pulp**

| Fruit Type | Eco-geographical zone | Moisture Content | Crude protein | Crude fat | Crude ash | Crude fibre | Carbohy-drates |
|---|---|---|---|---|---|---|---|
| ***O. Stricta* (Purple)** | Baringo (Marigat) | 91.56 ±0.01[b] | 1.41 ±0.01[a] | 0.41 ±0.01[a] | 1.61 ±0.01[a] | 1.43 ±0.01[c] | 3.57 ±0.01[d] |
| | Makueni (Sultan Hamud) | 92.82 ±0.01[e] | 1.40 ±0.01[a] | 0.42 ±0.00[a] | 1.61 ±0.01[a] | 1.39 ±0.01[a] | 2.35 ±0.01[b] |
| ***O. mona-cantha* (Green)** | Makueni (Nziu) | 91.89 ±0.01[c] | 1.52 ±0.00[c] | 0.48 ±0.00[b] | 1.71 ±0.01[b] | 1.63 ±0.01[d] | 2.77 ±0.01[c] |
| | Machakos (Kangundo) | 87.68 ±0.05[a] | 1.47 ±0.01[b] | 0.42 ±0.00 [a] | 1.71 ±0.01[b] | 1.71 ±0.01[e] | 6.98 ±0.01[e] |
| ***O. Ficus-indica* (Yellow)** | Laikipia (Matunda) | 92.60 ±0.02[d] | 1.53 ±0.01[c] | 0.41 ±0.00[a] | 1.77 ±0.01[c] | 1.41 ±0.01[b] | .27±0.01[a] |

The results are presented as mean± standard error of three separate determinations (n=3). Means within the same column with different superscripts are significantly different at ($p \leq 0.05$). LSD = Least Significant Difference at 5% level of significance

The pulp contained substantial amount of crude fibre, which could be of benefit to human health. The fibre works together with other bioactive compounds to aid in prevention of chronic diseases (Galati, *et al*., 2003).

Consumption of food with high dietary fibre is associated with numerous physiological and metabolic effects including increase in bulkiness of fecal matter, creation of favourable environment for intestinal microflora and prevention/control of obesity, coronary heart disease, colon cancer, type (ii) diabetes and atherosclerosis. Based on World Health Organization (WHO) who recommend 25 g/day of dietary fibre for adullts , cactus fruist would contribute to over 60 % (15g)  of the daily requirement for every 100g consumed. The green variety from Kangundo had the highest carbohydrate content (7%) that would be a good source of energy to the body. The results were comparable to other studied done by Kunyanga *et al*., (2014), Chiteva &Norman (2012) in Kenya as 1.32 % and 1.37 % respectively, and Saenz (2013) in Brazil as 1.32 %.

### 4.5 Mineral Composition

The mineral composition of the cactus varieties varied significantly at $p \leq 0.05$ with exception for Sodium. Cactus varieties were found to be a rich source of Magnesium, which was highest in the green variety (117.04 mg/100g). Zinc (2.39 mg/100g) and Iron (2.55 mg/100g) that were high in the purple variety. High magnesium level is suitable for strengthening bones. Juice for the purple variety was deemed suitable for anaemic patients attributed to its richness in Iron. The minerals in the cactus fruits could aid to alleviate micronutrient deficiency in the ASALs including Iron deficiency anaemia and Zinc deficiency with recommended dietary allowance of 8 mg/day and 18 mg/day for men and women respectively for Iron and 11mg/day for men and 8 mg/day for women for Zinc.

Moreover, the fruits were rich of potassium (106.21-203.71mg/100g) and are low in Sodium (14.95-19.02 mg/100g) that made them favourable for people with kidney problems and hypertension (Cota-Sánchez, 2016). Phosphorous was in trace amounts in the green variety that may be attributed to its deficiency in the soil. Generally, the purple variety exhibited the highest mineral composition that rendered it more suitable for health-conscious consumers. The results did not have major variations from those reported by Yahia & Mondragón (2014) in Mexicco, Chiteva& Wairangu, (2012) and Kunyanga *et al.*, (2014) in Kenya for similar varieties who reported ranges of (63.4-98.4 mg/100 g). for Magnesium, (1.4-3.8 mg/100g) for Iron and 2.6-3.6 mg/100g) for Zinc. The heavy metal including Lead (Pb) and Cadmium (Cd) were absent that implied absence of environmental pollutants.

The mineral content of the cactus varieties analysed are as shown in **Table 4.4.**

**Table 4.4: Cactus pulp mineral composition (mg/100g)**

| Fruit Type | Eco-geographical zone | Ca | Mg | Fe | Zn | K | Na | P |
|---|---|---|---|---|---|---|---|---|
| *O. Stricta* (Purple) | Baringo (Marigat) | 32.44 ±0.15$^{e}$ | 62.19 ±0.12$^{a}$ | 2.55 ±0.02$^{a}$ | 2.39 ±0.01$^{c}$ | 197.11 ±0.51$^{c}$ | 16.58 ±0.16$^{b}$ | 0.06 ±0.01$^{c}$ |
| | Makueni (Sultan Hamud) | 32.28 ±0.64$^{d}$ | 63.44 ±0.12$^{b}$ | 2.28 ±0.22$^{ab}$ | 2.39 ±0.01$^{c}$ | 199.83 ±0.38$^{d}$ | 14.95 ±0.28$^{a}$ | 0.09 ±0.01$^{c}$ |
| *O. monacantha (*Green) | Makueni (Nziu) | 30.43 ±0.08$^{c}$ | 117.04 ±0.12$^{d}$ | 2.18 ±0.03$^{a}$ | 2.30 ±0.01$^{a}$ | 108.69 ±0.25$^{b}$ | 19.02 ±0.16$^{d}$ | Trace |
| | Machakos (Kangundo) | 29.56 ±0.08$^{a}$ | 123.85 ±0.21$^{e}$ | 2.07 ±0.02$^{a}$ | 2.32 ±0.01$^{ab}$ | 106.21 ±0.14$^{a}$ | 16.86 ±3.25$^{c}$ | Trace |
| *O. Ficus-indica (*Yellow) | Laikipia (Matunda) | 29.69 ±0.13$^{b}$ | 109.60 ±0.21$^{c}$ | 2.11 ±0.02$^{a}$ | 2.34 ±0.01$^{b}$ | 203.71 ±0.28$^{e}$ | 14.95 ±0.28$^{a}$ | 0.09 ±0.01$^{c}$ |
| Heavy metals **(Pb, Cd)** - | | Absent | | | | | | |

The results are presented as mean± standard error of three separate determinations (n=3). Means within the same column with different superscripts are significantly different at ($p \leq 0.05$). LSD = Least Significant difference at 5% level of significance.

### 4.6 Specific Soluble Sugar Content of Cactus Pulp

The specific sugars of the cactus fruits analysed varied significant at a $p \leq 0.05$ with the yellow being the sweetest hence suitable for fresh consumption. The glucose content of the yellow variety was approximately 1.5-2 folds higher than in the other varieties. Sugar content is an important criterion of fruit quality since consumers prefers sweet fruit (Inglese *et al.*, 2017). There was significant difference at ($p \leq 0.05$) in the specific sugar content of the same variety that could be attributed to difference in their eco geographical zones. Most of the sugars present in the cactus fruit were of reducing type. Glucose, which is used as energy metabolite for brain and nerve cells, was highest in all varieties. The good sugar profile implies that the cactus fruits could serve as an energy source for the people living in the ASALs. The results were comparable to other studies done by Coetzer & Fouche, (2015) in South Africa and

Cota-Sánchez, (2016) in Mexicco.The specific sugars of the cactus varieties analysed are shown in **Table 4.5**.

**Table 4.5: Specific sugar characteristics of cactus pulp**

| Fruit Type | **Eco-geographical zone** | **Fructose(g/100g)** | **Glucose(g/100g)** | **Sucrose(g/100g)** |
|---|---|---|---|---|
| ***O. Stricta* (Purple Variety)** | Baringo (Marigat) | 1.16±0.01 $^{a}$ | 1.26±0.04 $^{a}$ | 0.11±0.06 $^{a}$ |
| | Makueni (Sultan Hamud) | 2.37±0.03 $^{d}$ | 2.58±0.15 $^{c}$ | 0.85±0.00 $^{c}$ |
| ***O. mona-cantha* (Green Variety)** | Machakos (Kangundo) | 1.64±0.01 $^{c}$ | 2.03±0.02 $^{b}$ | 0.65±0.03 $^{b}$ |
| | Makueni (Nziu) | 1.54± 0.00 $^{b}$ | 1.71±0.13 $^{b}$ | 0.64 ±0.05 $^{b}$ |
| ***O. Ficus-indica* (Yellow Variety)** | Laikipia (Matunda) | 2.66±0.02 $^{e}$ | 4.59±0.11 $^{d}$ | 1.04±0.03 $^{d}$ |

The results are presented as mean± standard error of three separate determinations (n=3). Means within the same column with different superscripts are significantly different at ($p \leq 0.05$). LSD = Least Significant difference at 5% level of significance

## 4.7 Phytochemical Composition of Cactus

The phytochemical content of the cactus varieties analysed are as shown in **Table 4.6**.

**Table 4.6: Phytochemical properties of cactus pulp**

| **Fruit Type** | **Eco-geographical zone** | **Vitamin C (mg/100g)** | **β-Carotene (mg/100g)** | **Total phenolics (g/100g G.A.E.)** | **Total flavonoids (g/100g Q.E.)** | **Antioxid-ant $ic_{50}$ (mg/ml)** |
|---|---|---|---|---|---|---|
| ***O. Stricta* (Purple)** | Makueni (Sultan Hamud) | 21.53 ±0.01 $^{b}$ | 0.01 ±0.00 $^{a}$ | 1.87 ±0.01 $^{c}$ | 0.16 ±0.00 $^{a}$ | 0.59 ±0.01 $^{a}$ |
| | Baringo (Marigat) | 20.85 ±0.19 $^{a}$ | 0.08 ± 0.01 $^{a}$ | 2.52 ±0.18 $^{d}$ | 0.22 ±0.02 $^{d}$ | 0.63 ±0.05 $^{b}$ |
| ***O. mona-cantha* (Green)** | Machakos (Kangundo) | 23.64 ±0.06 $^{c}$ | 0.55 ±0.02 $^{b}$ | 1.79 ± 0.00 $^{a}$ | 0.18 ±0.00 $^{c}$ | 1.58 ±0.08 $^{d}$ |
| | Makueni (Nziu) | 28.85 ± 0.28 $^{d}$ | 0.59 ±0.55 $^{c}$ | 1.79 ± 0.02 $^{a}$ | 0.16 ±0.02 $^{b}$ | 1.83 ±0.08 $^{e}$ |
| ***O. Ficus-indica* (Yellow)** | Laikipia (Matunda) | 24.82 ± 1.14 $^{e}$ | 2.47 ± 0.68 $^{d}$ | 1.84 ± 0.20 $^{b}$ | 0.23 ±0.00 $^{e}$ | 0.79 ±0.30 $^{c}$ |

The results are presented as mean± standard error of three separate determinations (n=3). Means within the same column with different superscripts are significantly different at ($p \leq 0.05$). LSD = Least Significant difference at 5% level of significance

Fruits contain non-nutritive compounds of health benefit to the consumer (Jana, 2012). The profile and content of these phytochemical compounds depend largely on the fruit type and the growth environment Cactus varieties showed a significant variation in phytochemical composition at $p \leq 0.05$. Cactus' varieties were rich in vitamin C (21.53-24.82 mg/100 g) with the yellow variety exhibiting highest Vitamin C content hence a good source of the vitamin. All the varieties exhibited good amounts of total phenolics (1.79 -2.52 g/100g GAE) and total flavonoids (0.16-0.23 g/100g Q.E.). Flavonoids help the fruits to survive harsh climatic conditions by protection against ultra-violet rays and drought stress (Dantas, *et al.*, 2015). The phenolic compounds have health-promoting effects in the body by reducing oxidative stress and inflammation (Yahia & Mondragón, 2014). The methanol extracts of the cactus varieties showed potential of free radical scavenging activity against DPPH with $IC_{50}$ value of (0.59-1.83 mg/ml), with the highest antioxidant activity being observed in the purple variety of 0.59 mg/ml. The lower the $IC_{50}$ value, the higher the potency of the variety as scavenging of DPPH implying a higher antioxidant activity. Yahia (2010) describes the purple variety to contain highest antioxidant activity attributed to high levels of bioactive compounds including the flavonoids. The results were not different from those obtained (Kunyanga *et al.*, 2014; Cota-Sánchez, 2016) for green, purple, and orange cactus varieties in Kenya and Mexico who reported total phenolic compound values of (1.58-2.76 g/100g) GAE and (0.19-0.74 g/100) Q.E for total flavonoids.

### 4.8 Sensory Analysis

Hedonic scale allowed the panellists to express their general impression of the cactus fruits and their attributes. Most of the parameters analysed including taste, aroma and general acceptability varied significantly at $p \leq 0.05$ in different ratios.

### 4.8.1 Sensory Evaluation for the Fresh Fruit Cuts

According to the results, the yellow variety (O. *Ficus-indica)* was most preferred due to its sweetness and small seeds, which are easy to crush. The green variety (O. *monacantha*) had least preference attributed to low sweetness. Fruits with high sugar and good appearance are most preferred by consumers to their tastes. The purple variety was intermediate in terms of the sweetness and seed crushability. Seed crushability is an important criterion to processors for juice extraction, as most processors prefer fruits with seeds that are easy to separate. The sensory evaluation results for the cactus fruits are shown in subsequent **Figure 4.2.**

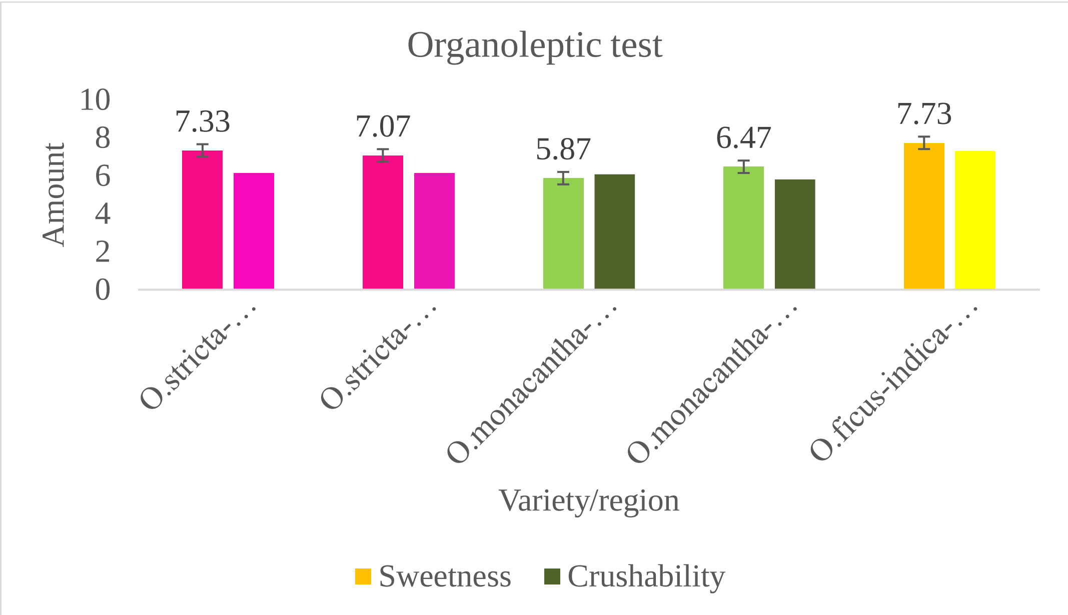



**Figure 4.2: Organoleptic characteristics of edible wild cactus fruits varieties in Kenya (9-Point Hedonic Scale)**

### 4.8.2 Juice Sensory Evaluation

The results for the juice sensory evaluation varied significantly at $p \leq 0.05$ for most of the sensory parameters including taste, aroma, flavour and consistency.to different ratios. The products with the highest means parameters were considered most preferred. The cactus pure drink was liked moderately in terms of appearance to a score of seven out nine on a 9-point hedonic scale. This was attributed to its richness in colour attributed to the colouring pigments including the betalains. Largely, cactus drink (100g/l) was most preferred in taste, aroma, and general acceptability to moderate liking on a 9-point hedonic scale. All the other products had a slight to moderate liking that implied suitability of the products for new product development.

The results on the consumer acceptability tests for the juices sampled are shown in **Table 4.7** below.

**Table 4.7: Cactus juices sensory Analysis based on 9-point Hedonic scale in reference to pure Cactus Drink (CD)**

| Product code | Appearance | Taste | Aroma | flavour | Consistency | General Acceptability |
|---|---|---|---|---|---|---|
| **100** | $7.07{\pm}0.13^{c}$ | $5.80{\pm}0.14^{a}$ | $5.93{\pm}0.13^{a}$ | $6.23{\pm}0.15^{b}$ | $6.13{\pm}0.14^{a}$ | $6.17{\pm}0.13^{a}$ |
| **101** | $6.33{\pm}0.16^{a}$ | $6.23{\pm}0.13^{b}$ | $6.00{\pm}0.13^{b}$ | $6.30{\pm}0.13^{c}$ | $6.60{\pm}0.17^{b}$ | $6.57{\pm}0.14^{b}$ |
| **102** | $6.50{\pm}0.17^{b}$ | $6.73{\pm}0.12^{c}$ | $6.50{\pm}0.13^{d}$ | $6.07{\pm}0.15^{a}$ | $6.73{\pm}0.16^{c}$ | $6.83{\pm}0.13^{c}$ |
| **103** | $6.33{\pm}0.16^{a}$ | $7.07{\pm}0.13^{d}$ | $6.37{\pm}0.14^{c}$ | $7.13{\pm}0.13^{d}$ | $7.03{\pm}0.14^{d}$ | $7.03{\pm}0.14^{d}$ |

The results are presented as mean± standard error of three separate determinations (n=30). Means within the same column with different superscripts are significantly different at ($p \leq 0.05$). LSD = Least Significant difference at 5% level of significance

100 = Pure cactus drink, 101= Sweetened (60g/l), 102= Sweetened (80g/l) and 103= Sweetened (100g/l).

### 4.8.3 Jam Sensory Evaluation

There was significant difference in terms of the appearance, aroma, and consistency of the jams evaluated against cactus pure jam. Cactus-Banana jam had the highest score for six characteristics evaluated with a moderate to very much liking on a 9-point hedonic scale. Pure cactus jam had moderate rating with an overall acceptability of 6.17 on a 9-point hedonic scale. The sensory evaluation results for the jam analyses are as shown in **Table 4.8**.

**Table 4.8: Sensory evaluation of cactus jam and blends at different rations with reference to pure cactus jam (CJ=200)**

| Products code | Appearance | Taste | Aroma | Consistency | Flavour | General Acceptability |
|---|---|---|---|---|---|---|
| **200** | $6.23\pm0.13^{b}$ | $7.17\pm0.13^{c}$ | $6.30\pm0.15^{c}$ | $6.17\pm0.14^{c}$ | $5.92\pm0.14^{a}$ | $6.67\pm0.15^{c}$ |
| **201** | $7.23\pm0.13^{d}$ | $7.50\pm0.12^{d}$ | $7.03\pm0.15^{d}$ | $7.30\pm0.13^{d}$ | $7.37\pm0.12^{d}$ | $7.40\pm0.13^{d}$ |
| **202** | $6.33\pm0.13^{c}$ | $6.10\pm0.14^{a}$ | $5.87\pm0.14^{b}$ | $5.87\pm0.14^{b}$ | $6.77\pm0.15^{c}$ | $6.37\pm0.18^{a}$ |
| **203** | $5.57\pm0.12^{a}$ | $6.27\pm0.14^{b}$ | $5.73\pm0.13^{a}$ | $5.73\pm0.13^{a}$ | $6.80\pm0.17^{b}$ | $6.40\pm0.15^{b}$ |

The results are presented as mean± standard error of three separate determinations (n=30). Means within the same column with different superscripts are significantly different at ($p \leq 0.05$). LSD = Least Significant difference at 5% level of significance.

200=Cactus jam, 201= Cactus-Banana, 202= Cactus-Mango and, 203= Cactus-Pawpaw jam.

# CHAPTER FIVE

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusion

Three edible wild cactus varieties were identified included the purple variety (*O. stricta*), the green variety (*O. monacantha*) and the yellow variety (*O. Ficus-indica*). They were different in colours attributed to the ratio and concentration of color pigments, which was highest in the purple, yellow and green respectively. Their shapes were distinct with *O. Stricta, O. Megacantha* having ovoid shape while *O. Ficus-Indica* was oblong. The purple variety (*O. Stricta*) had the highest fruit yields (11.07 $kg/m^2$) which is desirable to processors. *O. Stricta* and *O. Ficus-Indica* had juice extractability of over 50 % suitable for commercial exploitation. Opuntia *Ficus-Indica* was best for fresh consumption attributed to high soluble sugar levels. The fruits were of moderate pH of 4.0- 5.0 that classified them as medium acidic fruits.

The physicochemical analyses of the varieties indicated that they were good source of dietary fiber (> 1.30 %) that was essential for aiding bowel movement and preventing colon related illnesses. They were good source of minerals, which included Magnesium, Iron, and Zinc (> 62 mg/100g, 2.07 mg/100g and 2.30 mg/100 g) respectively that would aid to alleviate micronutrient deficiency including Iron and Zinc in the ASAls. More to that, the fruits were rich in reducing sugars including glucose and fructose hence suitable for providing energy metabolites for proper functioning of brain and nerve cells. Furthermore, the fruits were rich in total phenolics compounds and flavonoids that would be of health benefits to human health, which was superior in the purple variety (*O. stricta*). The purple variety showed a high level of inhibition of DPPH with $IC_{50}$ value of 0.59 mg /ml that indicated a high free radical scavenging activity (FRSA). The lower the $IC_{50}$ value, the higher the FRSA/antioxidant power of the variety.

Generally, the purple and yellow varieties were deemed the most suitable for commercial processing attributed to their superior technological properties including juice extractability, fruit density, pulp characteristics, mineral and phytochemical composition.

The processed products exhibited great characteristics in terms of flavor, taste, aroma, and consistency. As for the juice and jam products, the color was superior for the pure products thus, the pulp could be used either in isolation or with other food ingredients to develop a variety of strong coloured value-added products that would unlock the industrial potential of edible wild cactus for food processing.

Finally, yet importantly, the cactus fruits and their fruit-based products were highly rated by the panellists that indicated a higher consumer acceptability of the fresh and processed products. Liking of over five (5) on a 9-point hedonic scale indicated a great market potential for fresh and processed cactus fruits-based products.

## 5.2 Recommendations

Since identified edible wild cactus varieties had suitable characteristics suitable for commercial processing, development of effective processing technologies for their commercial exploitation should be done in Kenya. For sustainable fruit production, it is highly recommended to boost breeding programs of thornless cactus varieties that would intensify their production.

Given their suitability for commercial processing and potential application in development of functional foods, it will be indispensable to quantify the dietary fibre (soluble and insoluble). Additionally, cactus could have potential use as foods thus the study of the anti-nutrient's properties of the various parts of the fruits should be done as it is consumed with seeds.

Furthermore, it was recommended that a study of the effect of processing on the bioactive compounds of health benefits to be done. It was of great essence to examine their thermal stability during processing.

Lastly, the study recommends that the government policy makers should support the development of cactus value chain and promotion of spineless cactus farming in Kenya to alleviate food and nutrition insecurity concerns in the ASALs.

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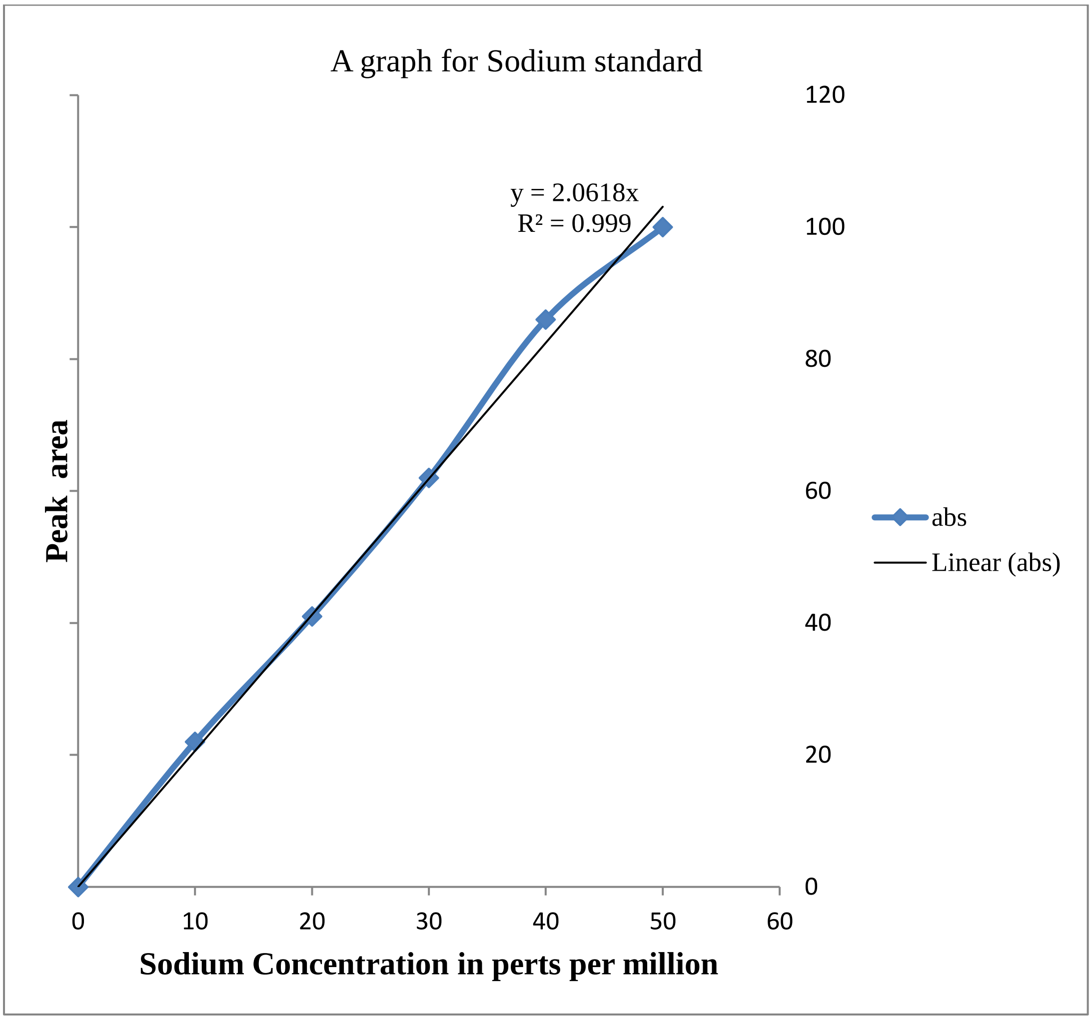
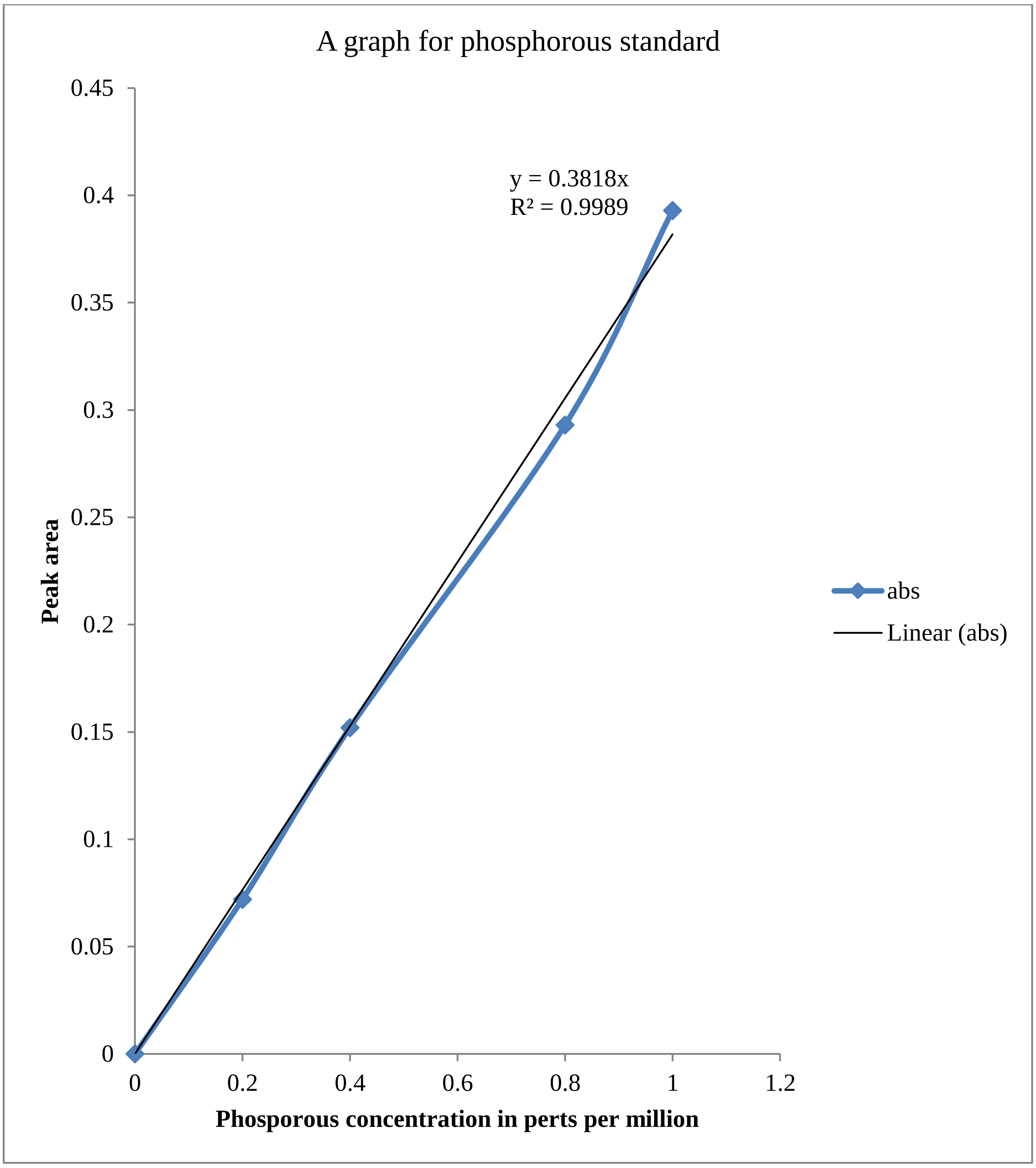
# APPENDICES

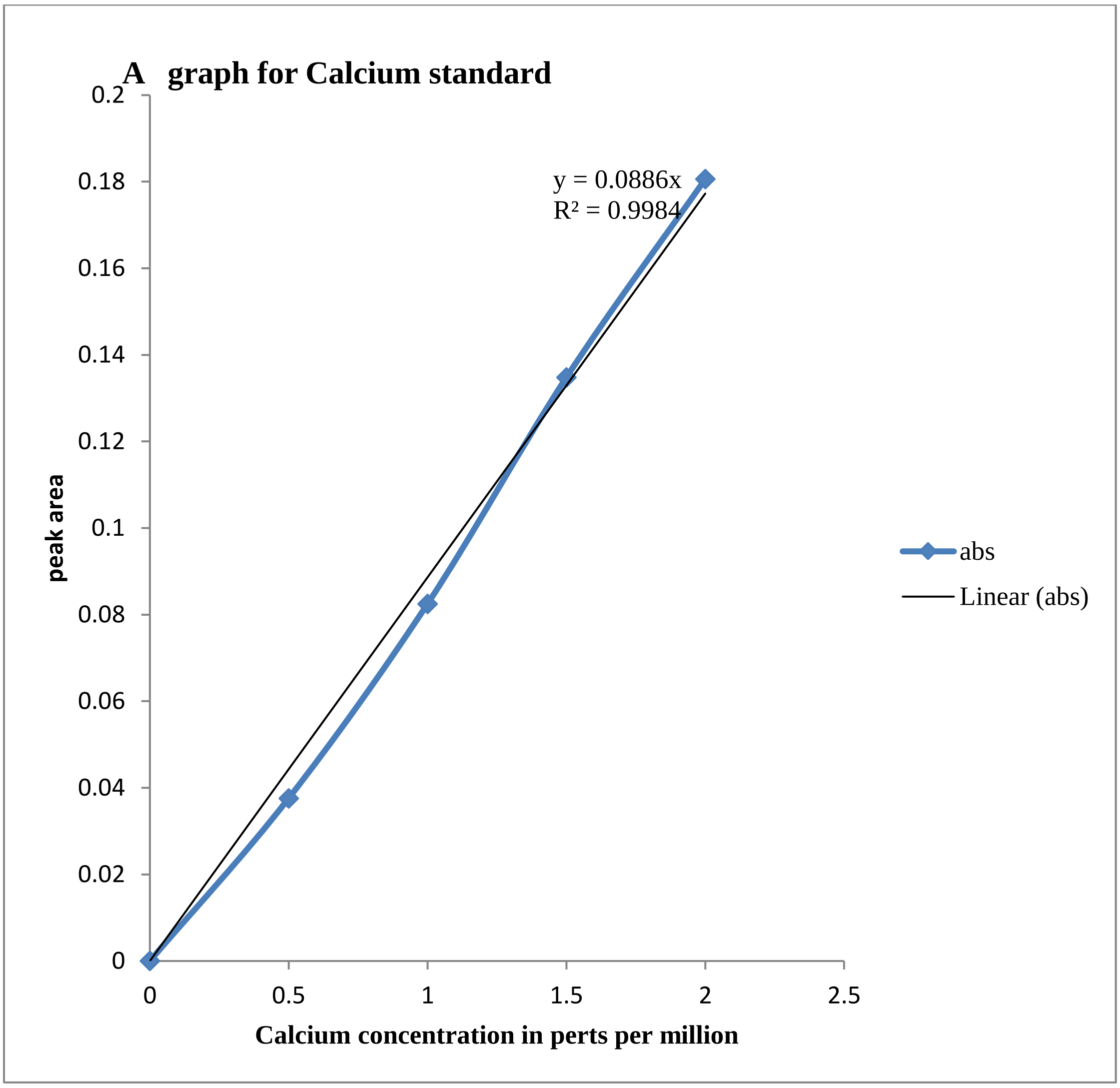
## Appendix I: Sodium Standard Curve



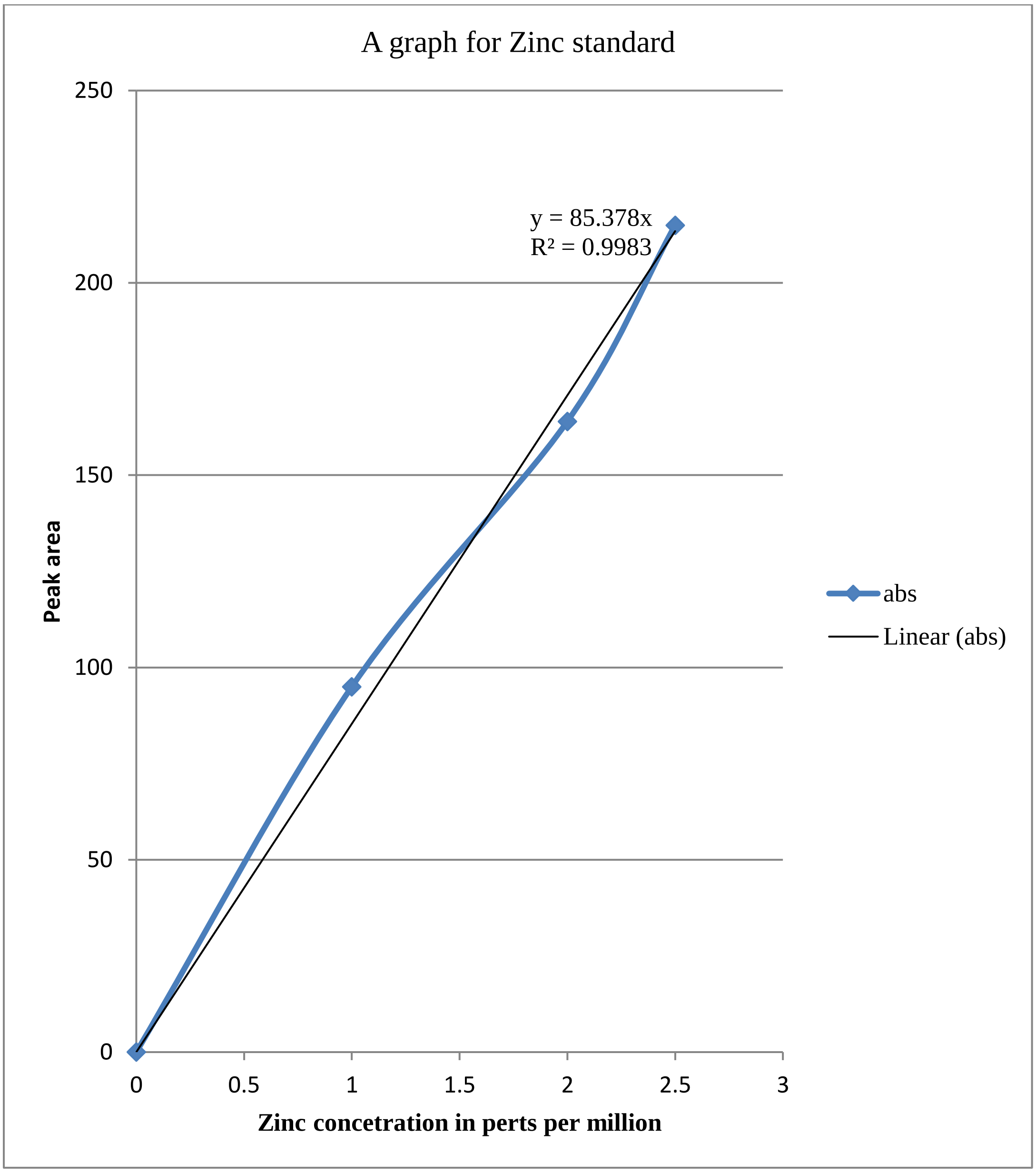
## Appendix II: Phosphorous Standard Curve



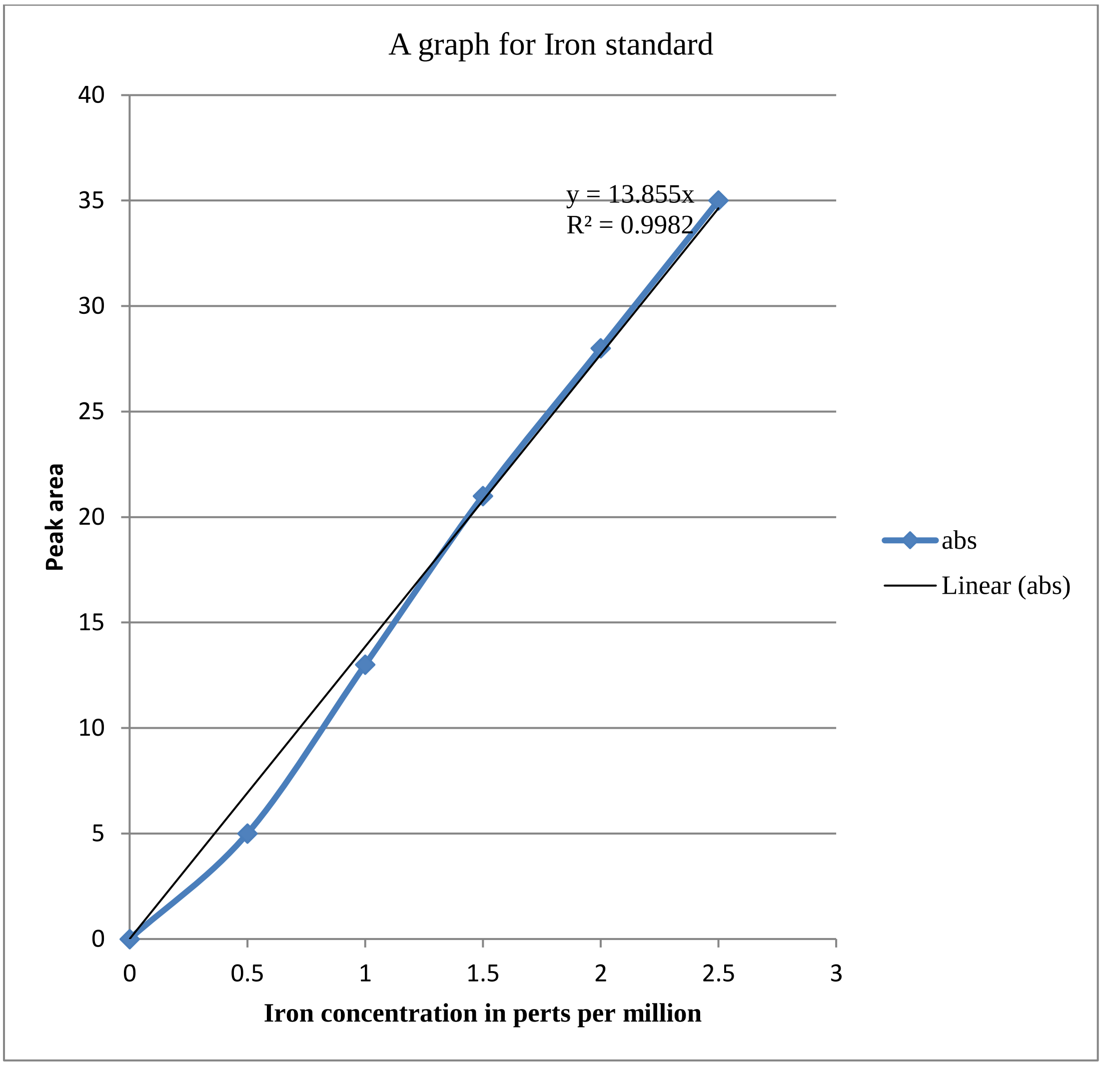
## Appendix III: Calcium Standard Curve



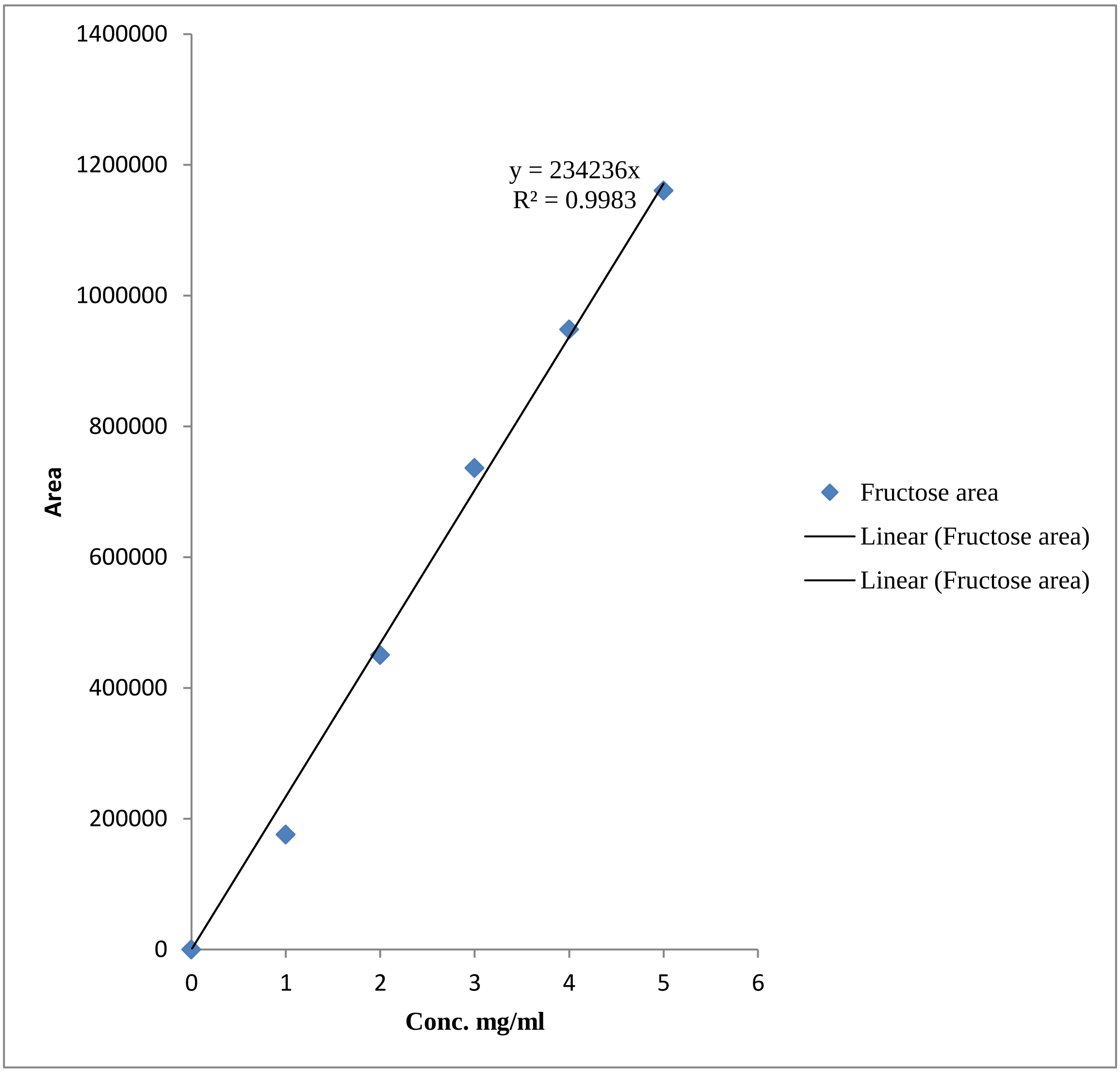
**Appendix IV: Zinc Standard Curve**



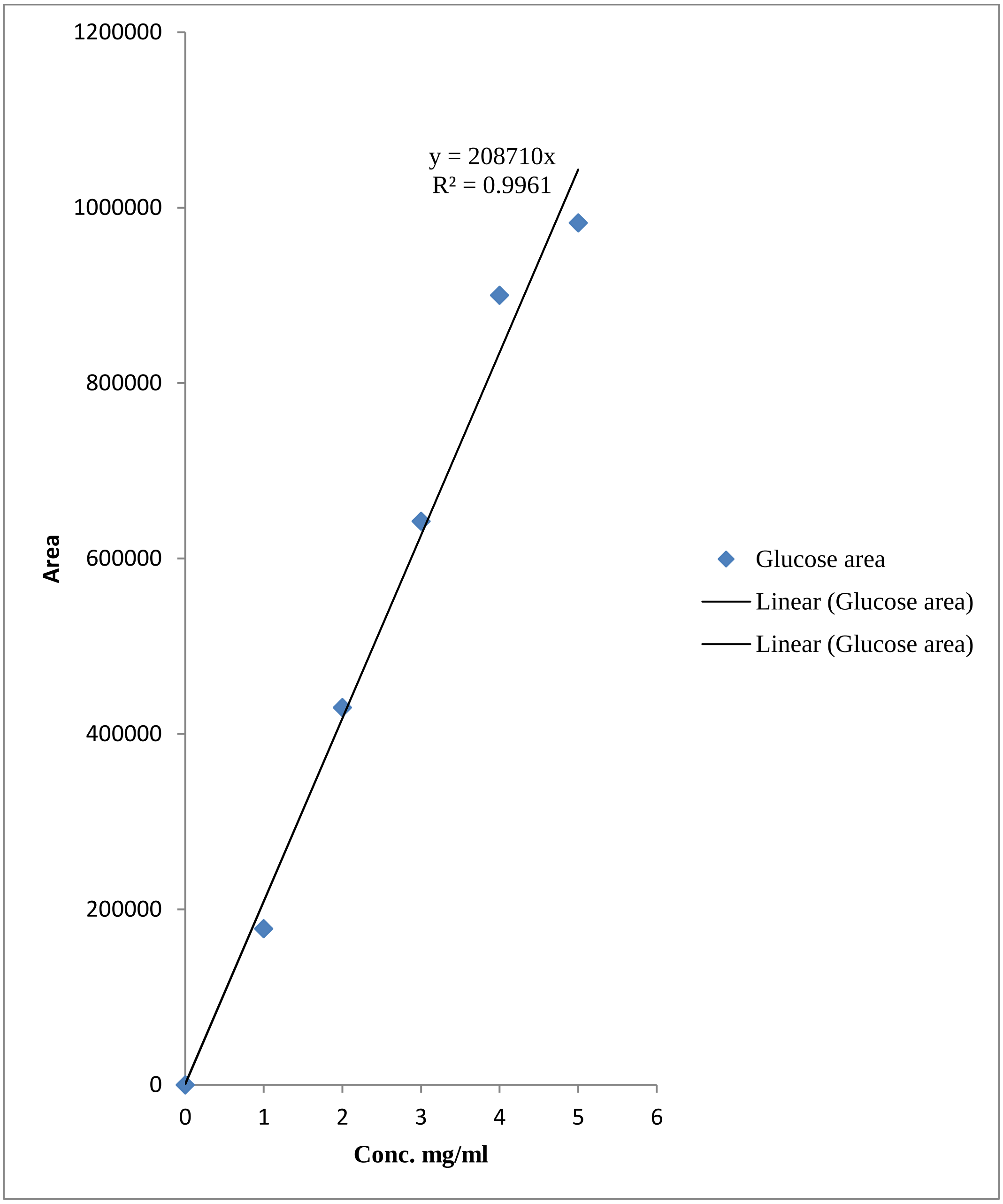
## Appendix V: Iron Standard Curve



## Appendix VI: Fructose Standard Curve

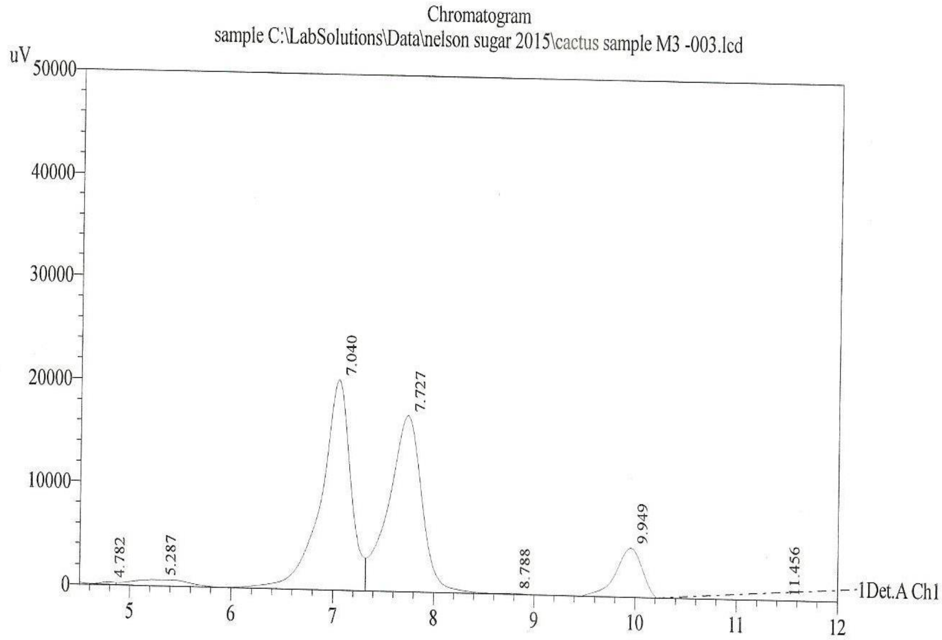


## Appendix VII: Glucose Standard Curve



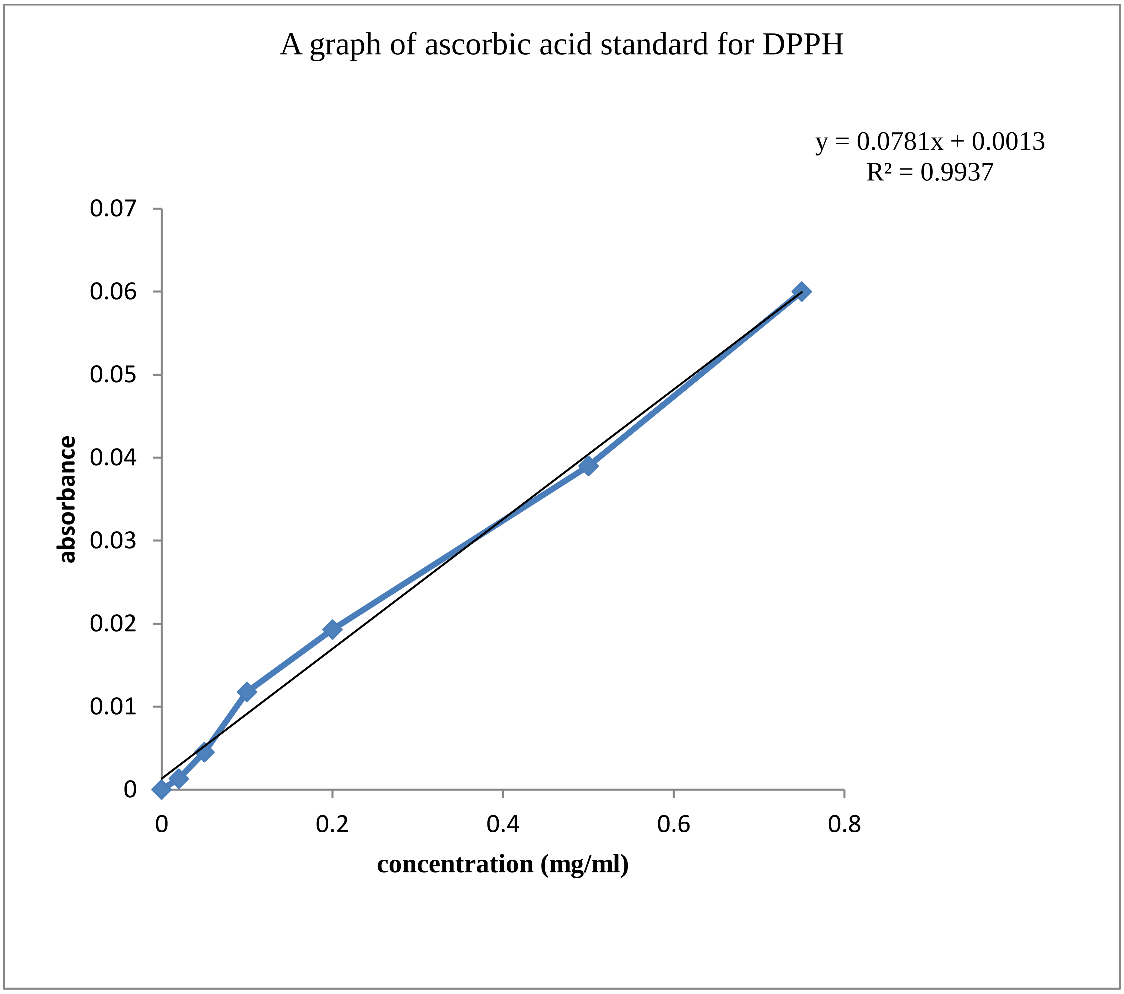
**Appendix VIII: Analysis of Sugars using HPLC**

## Appendix IX: Sugar Profile Chromatogram

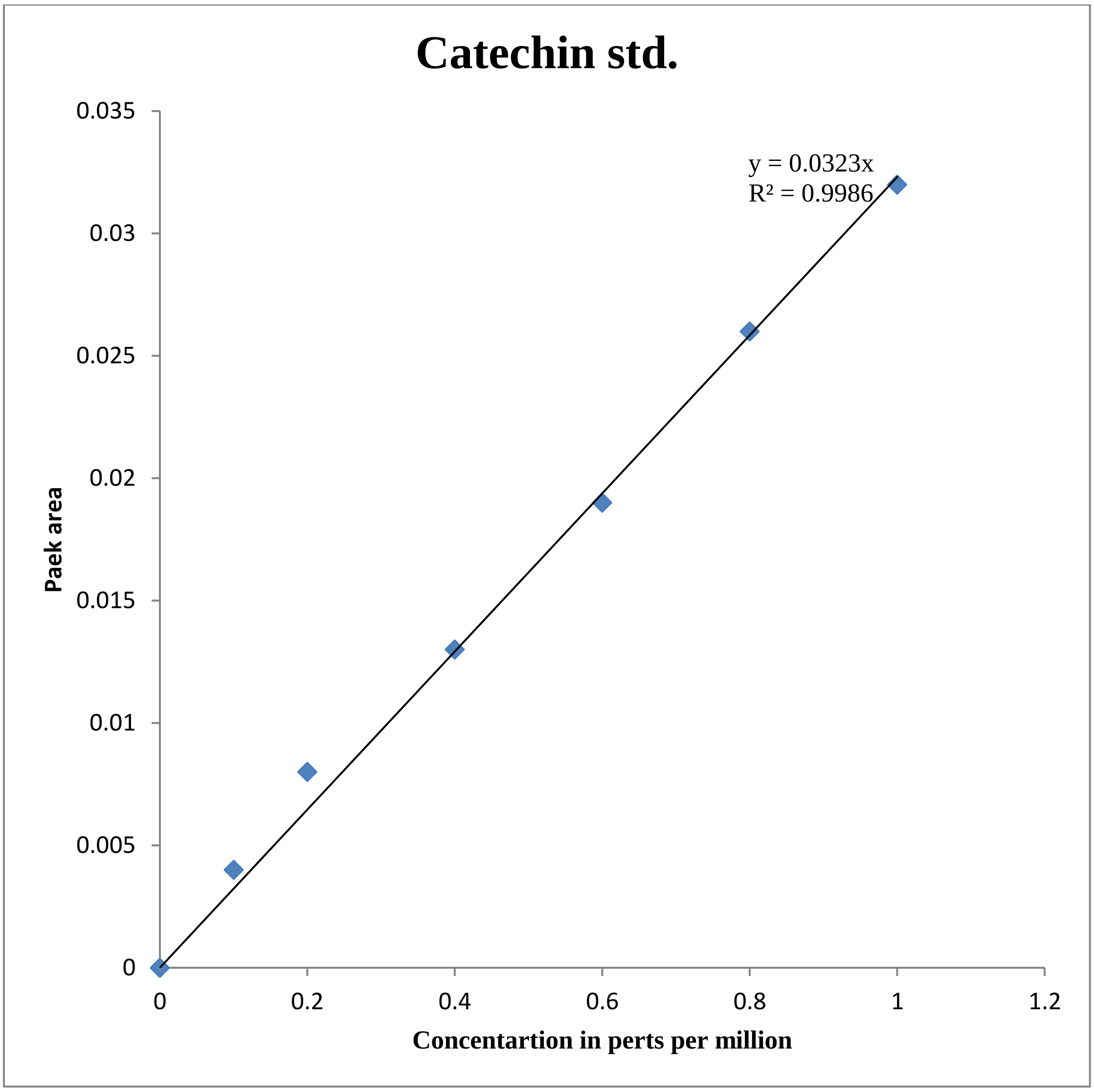



Time (mins)

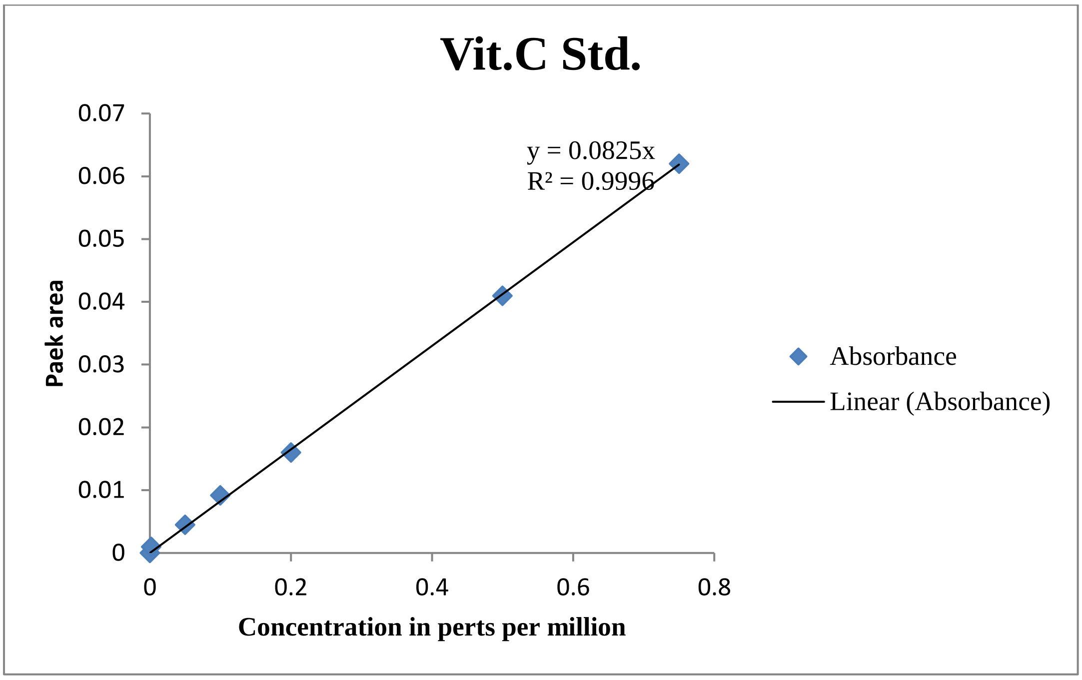
**Appendix X: Ascorbic Acid Standard Curve**



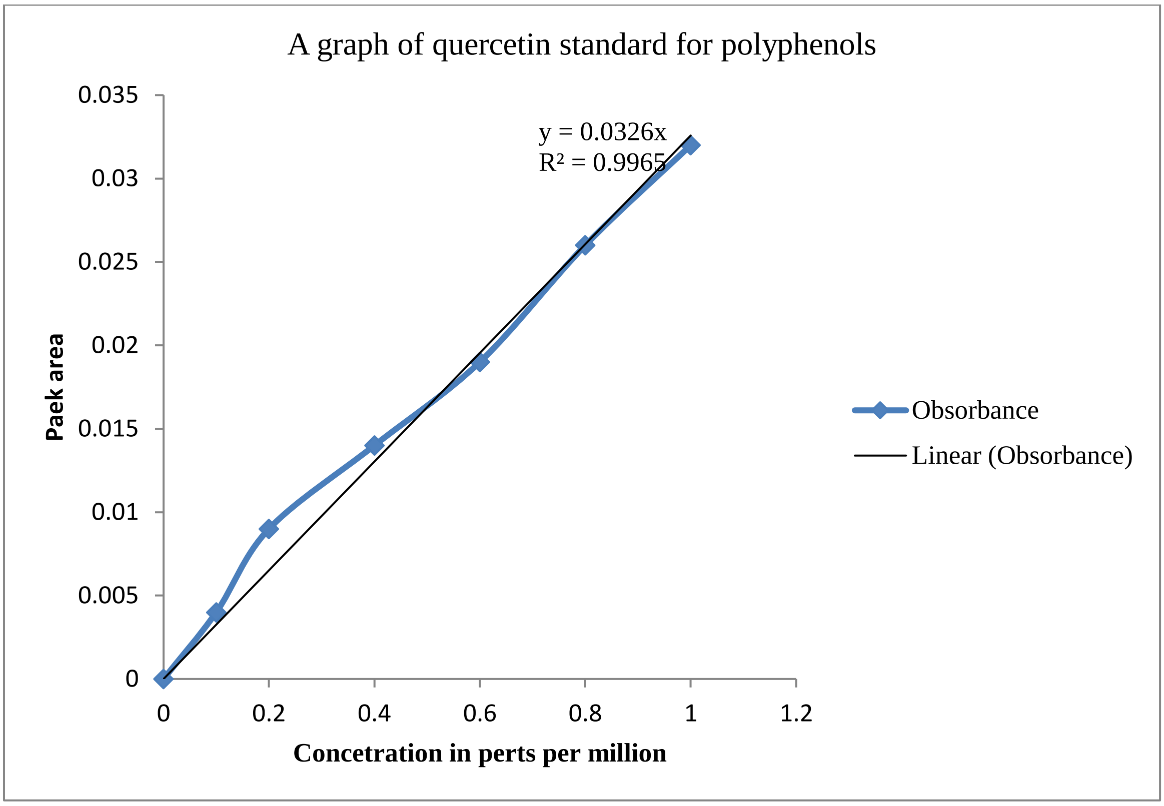
**Appendix XI: Catechin Standard Curve**



**Appendix XII: Vitamin C Standard Curve**



**Appendix XIII : Quercetin Standard Curve**



**Appendix XIV : Sensory Evaluation Questionnaire**

Date………………………Time…………….

Instructions

You are provided with four batches of different coded samples of fruit beverages to carry out sensory evaluation on them and express how much you like or dislike them. You are also provided with water to rinse your mouth after tasting each sample. Use the scale below to express your attitude towards the product colour, taste, flavour, and general acceptability of each of the samples by inserting the appropriate score in the space provided.

You are also requested to give any comments about the products and please try to be as honest as possible. Thank you.

**Description** **Score**

Like extremely..…………………………………………………….……….9

Like very much…………………………………………………….….…8

Like moderately ………………………………………………. ….………7

Like slightly ………………………………………………….…...........6

Neither like nor dislike…………………………………………...………5

Dislike slightly………………………………………………………….4

Dislike moderately …………………………………………….........3

Dislike very much ……………………………………………………………2

Dislike extremely ……………………………………………………………1

| Attribute | Juice Samples | | | |
|---|---|---|---|---|
| Sample codes | 100 | 101 | 102 | **103** |
| Appearance: | | | | |
| Taste | | | | |
| Aroma | | | | |
| Consistency | | | | |
| Flavour | | | | |
| General Acceptability | | | | |

Remarks

………………………………………………………………………………………

………………………………………………………………………………………

…………………………

| Attribute | Jam Samples | | | |
|---|---|---|---|---|
| Sample codes | 200 | 201 | 202 | 203 |
| Appearance: | | | | |
| Taste | | | | |
| Aroma | | | | |
| Consistency | | | | |
| Flavour | | | | |
| General Acceptability | | | | |

Remarks………………………………………………………………………………

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